The Mechanical Axes of the Wrist are Oriented Obliquely to the Anatomical Axes

INTRODUCTION:
Determining the osteoligamentous mechanical properties of the wrist is critical to understanding normal and pathological states, improving treatments for wrist disorders, constructing and validating mathematical models, and developing design specifications for wrist implants. Normal function of the wrist requires flexion, extension, ulnar deviation, radial deviation, and combinations of these motions. Recent studies of the Dart Throwers Motion (DTM) defined as radial extension to ulnar flexion, hint at the possibility of a mechanical behavior more complex than a simple two degree of freedom (DOF) joint, such as a universal joint.

The purpose of this study was to determine the previously undefined mechanical properties of the entire wrist joint. The moment-rotation relationship of the wrist joint was measured in 24 directions of wrist motion and then analyzed to determine values for neutral zone (NZ), range of motion (ROM), and stiffness (K ROM). We hypothesized that the principal axes of the wrist joint would be orientated in a direction different from the anatomical directions. We anticipate that these principal axes would be aligned with a DTM.

METHODS:
Six upper extremity cadaver specimens were obtained from three cadavers (F, age 59 years; M, ages 62 and 65 years), screened for gross anatomical defects and placed in a freezer at -20°C until 24 hours prior to mechanical testing. With fluoroscopic assistance, two Kirschner wires pinned the proximal radius to the proximal ulna in the neutral forearm position. The proximal radius and ulna were transected proximal to the Kirschner wires. Distally, the digits were disarticulated at the metacarpophalangeal joints. The proximal radius and ulna, and the metacarpal heads were potted in urethane compound. A specially designed loading jig was fabricated to apply a moment to the wrist in 24 directions of wrist motion. The jig was mounted to x-y linear bearing slides to allow an unconstrained moment application. Four constant force springs (4.45N each) were attached to the wrist flexors and extensors to simulate resting muscle tension.

Moment-rotation behavior was determined from 0 to 2 Nm in the anatomically defined directions of flexion, extension, ulnar deviation, and radial deviation. The remaining 20 directions of testing were defined at 15° increments within these anatomical directions.

The moment rotation curves in each direction were analyzed to determine neutral zone (NZ), range of motion (ROM), and stiffness (K ROM). A paired one-way ANOVA with the Holm-Sidak method for post-hoc analysis was used to determine if the mean ROM and NZ values were significantly different between directions of wrist motion. A P-value of 0.05 was defined a priori and adjusted for multiple comparisons. A one-sample t-test was then used to determine if the mean orientation of the principal axes differed significantly from the anatomical axes.

RESULTS:
The envelope of the average wrist ROM values was generally elliptical in shape, but was not oriented along the orthogonal axes of pure extension and pure flexion (Figure 1). The envelope of ROM values was oriented in a radial extension to ulnar flexion direction of wrist motion, significantly different (P < 0.001) by 26.6 ± 4.4 ° from the pure extension/flexion axis. Wrist NZ values paralleled the ROM values.

The envelope of K ROM values for the wrist was oriented orthogonally to the ROM envelope and its major axis was significantly different (P < 0.001) by -69.3 ± 8.4 ° from the pure axes of extension/flexion (Figure 2).

DISCUSSION:
The aim of this study was to determine the mechanical properties of the whole human wrist joint. Our finding that the mechanical axes of the wrist are oriented obliquely to the flexion/extension axes is consistent with the evolving consensus that the Dart Thrower's Motion (DTM) represents an important functional direction of wrist motion that may be unique to the human species. We found that the largest range of motion was in the direction of ulnar flexion (approximately 30° from pure flexion) and that the ROM varied continuously in 15 ° increments with the direction of wrist motion. Importantly, the overall orientation of the ROM envelope was in an oblique direction of radial extension to ulnar flexion. Consistent with this mechanical behavior was the finding that the orientation of the stiffness envelope was roughly orthogonal to that of the ROM.

This study provides insight into the mechanical behavior of the wrist and its function necessary to devise therapy protocols, construct and validate mathematical models, design accurate wrist implants, and to better understand the functional limitations of wrist injury and the expectations following wrist reconstruction.


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