Estimation of Optimal Carpal Contact in the Human Wrist from Multiple Static Articulation Postures

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Identifying wrist postures that maximize contact among the articulation bones has interesting potential applications in both athletic training and rehabilitation therapy. In such maximum contact postures, loads applied to the articulation distribute over wider contact areas, helping the wrist sustain impact more effectively.

Because of the wrist's complexity – eight small carpal bones located between five metacarpals and two forearm bones – analyses of wrist contact have typically been limited to either multiple two-dimensional postures (Anderson1995), or single three-dimensional (3D) postures (Thoomukuntla2005, Carrigan2003). However, novel techniques (Marai2006) make possible the acquisition and analysis of subject-specific 3D wrist geometry, kinematics and contact across multiple static postures.

We developed a subject-specific kinematic model of the carpus to analyze in vivo contact in the carpus. The geometry of six articulation bones was extracted from a reference computed tomography volume image. The cartilage geometry was computationally modeled using kinematic constraints and a validated deformable model. The data collected in vivo was coupled with numerical simulation and the total contact among the articulation bones was computed for seven individual postures.

We found that contact among the bones varied between 187.76mm^2 and 848.69mm^2, with most postures ranking below 25% of the largest contact value. These results suggest the existence of a unique maximum-contact (close-pack) posture in the wrist, located at cca. 15º ulnar deviation.

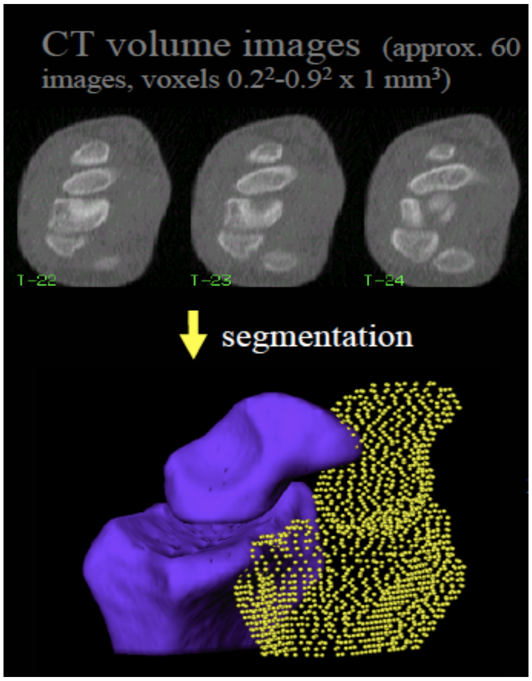
Data Acquisition

The wrist of a male volunteer was imaged using a GE Hispeed Adv. CT scanner at 0.94 x 0.94 x 1 mm^3. Seven postures were imaged: 40^o flexion, 40^o extension, 30^o ulnar deviation, 10^o radial deviation, and combinations of these motions.

An additional high-resolution scan (0.31 x 0.31 x 1 mm^3) was acquired in a neutral posture

Methods

Through manual segmentation, thresholding, and user interaction, bone surfaces are extracted from the high-resolution reference CT volume image [28]. Bone surfaces are further modeled as NURBS surfaces using the Geomagic software package [43]. Next, each bone surface is tracked with sub-voxel accuracy through the sequence of remaining CT volume images. The tracking procedure reports relative bone motion from one articulation pose to another. The motion of each wrist bone is reported in coordinates relative to the fixed forearm.



The model of the wrist includes three-dimensional geometric data of the eight carpal bones, two forearm bones, and five metacarpals. We use the bone geometry and sampled kinematics to generate cartilage maps. We generate cartilage maps from the fifteen bone surfaces and their kinematics (2mm proximity threshold, 1% compressed thickness). Cartilage maps are characterized by their location, thickness, and stiffness coefficient. They are modeled and simulated as incompressible, deformable height fields. For each joint pose and pair of articulated bones we compute and report the location and size of the articular cartilage contact.

Results

We found that contact among the bones varied between 187.76mm^2 and 848.69mm^2, with most postures ranking below 25% of the largest contact value. These results suggest the existence of a unique maximum-contact (close-pack) posture in the wrist, located at cca. 15º ulnar deviation.

Posture/ Bone	1	2	3	4	5	6	7
Cap	59.35	152	51.43	37.69	8.36	76.27	126.29
Lun	43.46	169.32	18.48	42.62	6.97	105.35	93.23
Rad	124.17	123.91	70.28	6.62	0.25	65.03	54.49
Sca	120.04	250.3	87.78	30.29	8.11	52.04	284.01
Tpd	24.74	77.69	17.98	39.49	68.15	77.98	81.76
Tpm	6.04	75.47	0.00	31.05	62.33	24.19	62.43
Total	377.80	848.69	245.95	187.76	154.17	400.85	702.20

Discussion and Conclusion

We have developed a subject-specific kinematic model of the carpus and we have performed a deformable analysis of articular contact. We found large variation of contact with posture and maximum contact at approximately the knuckle posture. These findings have potential application to athletic training and rehabilitation therapy.

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