Introduction: Techniques for modeling the anatomy and kinematics of the wrist are becoming increasingly sophisticated. CT(1) and MRI(2) image-based markerless registration methodologies yield detailed digital bone surfaces and accurate three-dimensional (3-D) kinematic data suitable for patient-specific modeling. At this point, however, none of the current techniques are capable of generating accurate 3-D cartilage surfaces, which are crucial to understanding the normal and pathologically altered bony articulations in the wrist. Our approach for addressing this problem is to combine μCT-generated cartilage thickness maps with CT-generated carpal bone surfaces(3). In this study we evaluated the fit of μCT-generated cartilage surfaces to CT-generated bones, the scalability of cartilage thickness, and cartilage surface collision/penetration during joint motion.

Materials and Methods: Four cadaver wrists (2M, 2F, age 65 ± 3 yrs) were CT scanned in 13 positions of pure and combined flexion, extension, radial and ulnar deviation. The carpal bone surfaces were individually segmented and the kinematics of the capitate, lunate, and scaphoid were determined using markerless registration(1). The carpal bones and distal radius were separated via careful dissection, and high-resolution (60 μm voxel) 3-D images of the bones and their surrounding soft tissues were generated via micro-computed tomography (μCT 40, Scanco, CH). Soft tissue “shells” were generated from the μCT images via thresholding and manual editing (Mimics, Materialize, Ann Arbor, MI); the inner surfaces of the shells were exported as μCT-generated bone surfaces. Individual cartilage facets (e.g. Fig. 1, lunate and scaphoid facets on the radius) were manually segmented from the soft tissue shells using Geomagic Studio (Geomagic, Inc., Durham, NC), and a shortest distance algorithm in Geomagic Qualify was used to quantify cartilage thickness.

Results: Fidelity of the CT and μCT bone surfaces was high, with centroid distances within 0.29 ± 0.15 mm and inertial axes within 4.9 degrees of each other. Regions where one bone surface was larger than the other were randomly distributed, though the CT-generated bone surfaces did fall outside the μCT-generated surfaces by an average of 0.178 mm. Accordingly, the CT bones were on average 196 ± 106 mm3 (or approximately 8%) larger than their μCT counterparts. (Fig. 2)

Discussion: This study was performed to evaluate the use of 3-D cartilage surfaces for the purposes of patient-specific modeling. Specifically, we evaluated the application of 3-D μCT-generated cartilage surfaces to carpal bone models generated using a clinical CT scanner. Our technique yielded high-resolution cartilage surfaces that fit the CT-generated bone surfaces well. However, carpal cartilage thickness did not scale simply with bone volume, and there was a surprising amount and extent of cartilage-cartilage and cartilage-bone penetration during kinematic animation of the bones. We suspect this is due to a combination of small errors in μCT and CT bone alignment, the error inherent in calculating kinematics using markerless bone registration (~0.5 mm translation and 0.5 deg rotation (3)), and perhaps some cartilage compression, which was not accounted for during the animation. In summary, μCT can be used to generate far more accurate cartilage surfaces than current technologies that utilize from clinical CT or MRI images.


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