SEGMENTED CARTILAGE MODELS VERSUS CARTILAGE MODELS PROJECTED FROM BONES

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INTRODUCTION:

Calculation of *in vivo* joint forces and contact pressure distributions is complex. Several methods have been developed with combinations of in vivo imaging, kinematic studies, and computational models to evaluate joint mechanics. One method of model construction uses computed tomography scans to develop 3D models of the bones in the joint. Cartilaginous tissue is then simulated using a linear, normal expansion of the bone surface (sometimes referred to as a projected cartilage layer).[1] However, the thickness of the actual cartilage layer can be non-uniform. Thus, the morphology of the projected cartilage surface may not match the anatomical morphology. Using MRI data, it is possible to directly segment the cartilage surface. We hypothesized that joint models using projected cartilage will yield different surface contact forces than will joint models with cartilage surfaces segmented from MR images. A study was performed to determine the differences in joint mechanics measures between bone models with projected cartilage versus models with segmented cartilage.

METHODS:

Three cadaver wrists were imaged in a 9.4T MRI scanner. Slices were taken every 1 mm, with in-plane resolution of 0.12 mm, using a gradient recall echo sequence. Images were obtained without loading the wrist. Using these images, we extracted surface models that represented only bone tissue and surface models that included the bones and cartilage that surrounded the bones. Models of the scaphoid, lunate, and distal radius were created by both methods for each specimen. For the bone only models, articular surfaces were created using a vector-normal projection from the bone model surface of 1 mm.

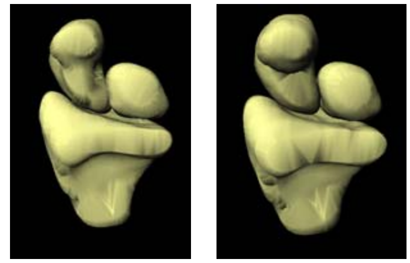
A second set of MR images was obtained during the simulated grasp. This image set was used to determine the loaded position and orientation of the bone models. Experimental pressure data was obtained during simulated grasp using a electronic pressure sensor (Model 4201, Tekscan, South Boston, MA).

Evaluation of contact mechanics during simulated grasp for both the segmented and projected surface models was performed in a multi-body contact program (Joint_Model, Columbia University).[2] This program calculated the contact area, force, and contact pressure distribution, based on interpenetration of the models, and the specified elastic modulus, and cartilage thickness. For this study, the effective cartilage modulus was set at 4 MPa and the cartilage thickness was 1 mm on each bone surface (inward on segmented models and projected outward from bone-only models). The program provided quantitative results and visual representation of contact stress distribution. This data was analyzed for similarities and differences between methods. Both sets of data were compared to the pressure data from the Tekscan sensor.

RESULTS:

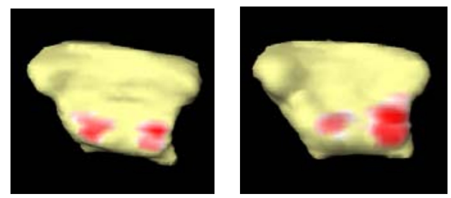
The geometries of the projected and segmented cartilage models were similar and qualitatively appeared to be accurate (Figure 1). It was visually apparent that the projected models produced different contact pressure distributions than the segmented models (Figure 2). Projected model articulations generally showed larger contact areas with higher peak pressures (Table 1).

The segmented model data was closer to the Tekscan results. Although neither modeling approach precisely matched the Tekscan data, the projected data showed substantially larger differences than the segmented data (Table 1). In some articulations, the projected models produced pressure measurements that were higher than the Tekscan data, and in some cases lower.



(a) **(b)**

Figure 1. Manually Generated Bone Models for Specimen 2. (a) Segmented Cartilage (b) Projected Cartilage



(a) **(b)**

Figure 2. Sample Pressure Distributions for Specimen 1 Radius. (a) Segmented Cartilage (b) Projected Cartilage

Table 1. Example Data Output (Specimen 1 & 2)

		Specimen 1			Specimen 2		
Joint	Method	Peak Press. (Mpa)	Force (N)	Area (mm)	Peak Press. (Mpa)	Force (N)	Area (mm)
R-S	Tekscan	1.5	44.8	61.7	1.2	7.0	18.1
	Segment	1.9	36.2	42.2	1.8	48.0	48.3
	Project	4.4	198.5	88.0	2.4	72.1	58.2
R-L	Tekscan	0.7	9.8	18.1	0.4	1.9	7.3
	Segment	2.1	28.4	32.1	1.5	35.4	50.4
	Project	3.2	55.4	40.2	2.8	60.8	51.6

DISCUSSION:

Though the geometry of projected cartilage models appeared to be good, overestimation and underestimation of joint forces occurred in the projected cartilage models. Furthermore, the results for each articulation in the projected models was not consistent from specimen to specimen, making it difficult to draw a conclusion about the effect of projected-cartilage modeling on a particular articulation.

Although the segmented cartilage models showed differences from the Tekscan data, the results were consistently closer than the projected cartilage results. It is important to note that there is also error attributed to the experimental technique and the accuracy of the Tekscan sensor. However, our studies indicate that the Tekscan sensor is generally accurate to within 10% of the actual values of force in such experiments.

The results of this study indicate that whenever possible, the cartilage surface should be segmented from an MR image set. When it is necessary to use projected cartilage models the investigators should be aware of possible errors. The applied loading and/or kinematics, combined with the complex geometry of the bone makes these models extremely sensitive to cartilage surface geometry. Although CT may yield more accurate models of bone (only), the MR data allows accurate modeling of both the bone and the cartilage surface.

The results of this study apply not only to surface modeling of joints, but also to discrete-element models (rigid-body spring models),[3] distance-based contact area estimates calculated from bone proximity,[4] and finite element models of joint contact.

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