COMPARISON OF CT-TO-FEA METHODS FOR PREDICTING STRAINS IN A LONG BONE

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INTRODUCTION:

Rapid patient-specific mesh generation for finite element analysis of bone is important for presurgical planning of complicated procedures such as distraction osteogenesis. Noninvasive imaging methods such as computed tomography (CT) have become useful tools for assisting surgeons, but do not provide detailed analysis of the material properties of bone. Voxel-based finite element model-derived estimates of bone strength are reasonably accurate for determining compressive strength[1]. Rough gradient material property voxel-based models have been shown to yield comparable results to geometry-based models[2]. Different equations have been used to define material properties of elements based on CT Hounsfield Unit values[3]. The purpose of this study was to compare the accuracy and speed of uniform material property geometry-based and nonuniform material property voxel-based mesh generation methods in predicting the strains of a canine radius loaded in four point bending. It was hypothesized that a voxel-based method would yield a mesh with greater speed and accuracy.

METHODS:

A single left radius was harvested from a 25 kg adult mongrel dog. CT imaging was conducted to yield a 188-image stack with a slicing dimension of 1 mm and an in-plane dimension of 0.16 mm/voxel. The CT data set was used for generating two finite element models.

The geometry-based model was created as follows: the dicom CT data were used to build a series of contours, which were manually smoothed and converted into non-uniform rational B-spline (NURBS) surfaces by lofting the curves. TrueGrid (XYZ Scientific, Livermore, CA) was then used to create the mesh as contained within the 3D NURBS surfaces. Uniform material properties were prescribed as reported for the adult canine radius[4] (E=24.5 GPa, ν=0.39).

The voxel-based model was created as follows: custom code written in Matlab was used to read the dicom data and build a mesh based on Hounsfield units of voxels. A total of 169 different elastic moduli were used to describe elements within the model, according to the intensity of the Hounsfield unit for each voxel[4] (Fig. 1). Uniform Poisson's ratio of ν=0.39 was used throughout the model.

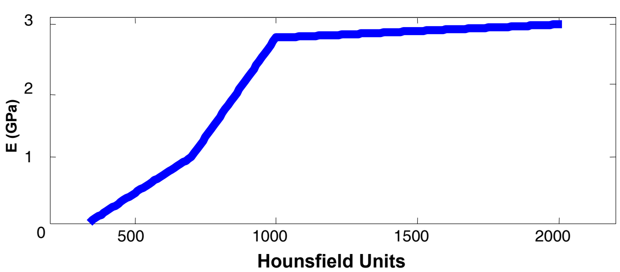

Figure 1: Graphical representation of algorithm used to convert CT Hounsfield units to elastic moduli.

The canine radius was mechanically tested in four-point bending while recording strain from three fully-encapsulated strain gages (Vishay Micro-Measurements, Raleigh, NC) applied around the midshaft periphery (Fig. 2). The two computational models (Fig. 3) were constrained and loaded in four-point bending to mimic the mechanical testing regimen. Strain at the midsection was averaged across nodal axial strains corresponding to each of the three gage sites. Elements representing the periosteum[5] around the bone were not considered in the gage averages for the voxel-based model, as this tissue was removed before gages were applied.

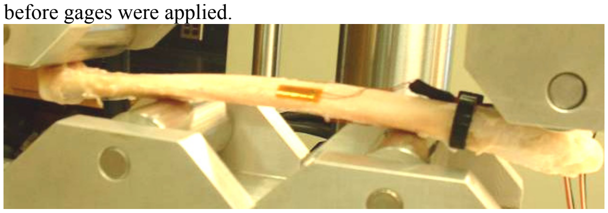

Figure 2: Image of canine radius in four-point bending apparatus.

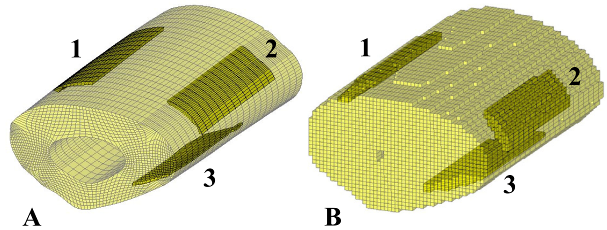

Figure 3: Detail of computational models. Shaded elements are colocalized with strain gages (1 - 3). Nodal strain averages from these sections presented below. A) Geometry-based B) Voxel-based.

RESULTS:

Both computational models predicted tensile strains with higher accuracy than compressive strains (Fig. 4). For tension, the voxel-based method provided a closer strain than the geometry-based model at gage site 1. For gage site 2, the geometry-based model provided a closer prediction of strain as compared to mechanical testing. In compression, there was little difference in the models' ability to predict strain at gage site 3.

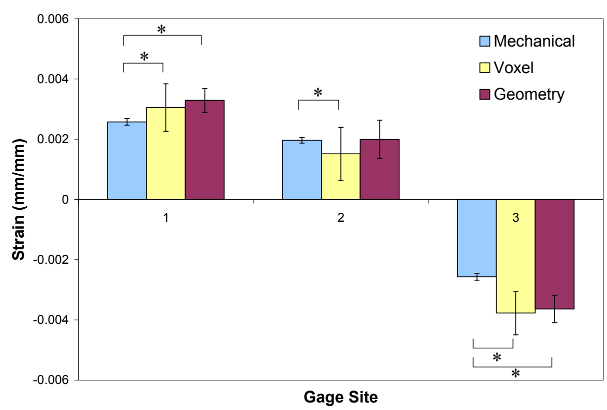

Figure 4: Results of strain gages (Mechanical) and computational (Voxel, Geometry) models (* p < 0.05). Data are presented as mean ± standard deviation of nodal strains at strain gage locations.

DISCUSSION:

Both mesh generation methods produced models suitable for finite element analysis. The discrepancy of the models' prediction of strain at gage site 3 is possibly due to muscle and other tissue that remained until mechanical testing. Once the custom code was developed, the voxel-based method was used to automatically create a mesh in under 10 minutes, whereas the geometry-based method required user interaction over the course of several days to build a mesh. Solution time was roughly two hours for both models on a desktop PC. Future work will involve mesh refinement of the computational models and further application of the voxel-based method to other tissues.

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