A FINITE ELEMENT STUDY OF THE STRUCTURAL EFFECTS OF LESION MORPHOLOGY IN A BIPEDAL ANIMAL MODEL OF FEMORAL HEAD OSTEONECROSIS

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Introduction:

Alterations to the internal biomechanics of the femoral head in the presence of an osteonecrotic lesion cause the structural femoral head collapse that characterizes human femoral head osteonecrosis. The bipedal emu has been an attractive animal model in which to replicate this disease characteristic, although lesion-specific stress changes in the emu femoral head remain unexplored. In order to evaluate changes in emu femoral head stresses resulting from different cryoinsult-induced lesions, a 3D structural finite element (FE) model was developed. Five different lesions were simulated, and deviations in stress patterns associated with each lesion were compared to a baseline (normal) case.

Methods:

A high resolution (0.1 x 0.1 mm in-plane; 0.3 mm slice spacing) CT scan of an emu proximal femur was acquired and the outer femoral surface was segmented in Matlab [1]. An isosurface enclosing the resulting set of binary segmentations was exported to PATRAN for localized mesh refinement. Mesh density in the femoral head was increased to allow for simulation of smooth ellipsoidal lesions similar to those obtained experimentally. This refined surface mesh was then filled in with 4-noded tetrahedral elements, and a 1 mm thick layer of shell elements was added to represent the subchondral plate.

Prior to generation of Hounsfield-based Young's modulus for each element in the model, a spherical averaging filter (r = 1.5 mm) was applied to the Hounsfield values to impart a continuum representation, in view of the coarse trabeculation of emu cancellous bone and the fine resolution of the CT scan. These

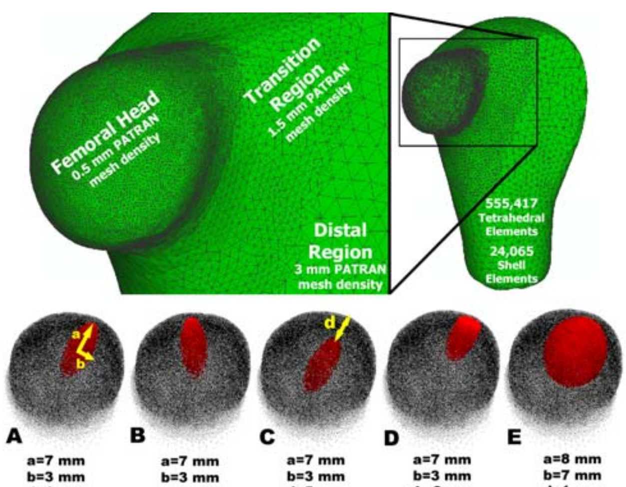

Figure 1. Surface mesh density was increased in the femoral head region for modeling of simulated lesions (shown in red, in a medial-to-lateral view of the emu femoral head). Ellipsoidal lesions are defined by major (a) and minor (b) axes and by the depth (d) from the subchondral bone.

Young's modulus values were binned into 10 material property definitions (E = 100-600 MPa). Gait analysis-derived resultant hip contact forces were distributed using a cosine-cubed distribution over contact patches measured with pressure sensitive film [2].

Matlab was used to simulate cryoinsult lesions by reducing the Young's modulus to 25% of the Hounsfield-based normal value for elements in an ellipsoidal region (Figure 1). Stress-to-strength ratios (SSR) were computed for each element ($\sigma_{maxprincipal}/\sigma_{yield}$). Increases in this ratio as compared to the baseline case reflected structural compromise due to the lesion.

Results & Discussion:

SSR values in the femoral head cancellous bone showed consistent increases over the baseline case in the presence of a lesion, but the most notable change was a shift to higher SSR values in the subchondral plate. Increase in lesion size caused the largest shift, and both depth (from subchondral bone) and spatial position had significant effects on the SSR values associated with narrow lesions (Figure 2). Because femoral head collapse is a fatigue related process, small changes in SSR value can have major effects on the structural integrity of the femoral head.

In addition to the ability to identify (in terms of SSR changes) shifts towards structural susceptibility for collapse, the present FE formulation can be augmented to test for different failure criteria to reflect other measures of lesion severity.

References:

[1] Anderson DD, et al. *Comput Aided Surg* **9**(3), 2004.
[2] Reed KL. PhD Thesis, University of Iowa, 2003.

Acknowledgements:

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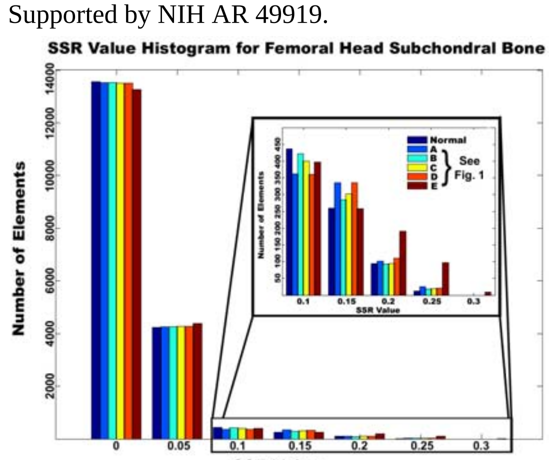

Figure 2. Histogram of SSR values for elements in the femoral head subchondral plate during the increment of gait with the highest hip contact forces.