POTENTIAL AND LIMITATIONS OF A REFINED MECHANOSTAT MODEL OF BONE TRANSFORMATION

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Introduction

Bone is a living tissue that shows adaptation in shape and structure, if the prevailing load conditions are significantly changing. One example is the loss of bone mass of astronauts under microgravity, which can already be measured after missions of medium duration. The underlying remodeling processes are still under investigation. Remodeling laws derived from experimental data are able to explain morphologic adaptation of the microstructure of trabecular bone to external loads. However, the question whether such mechanistic algorithms can be transferable to the bone shape level is yet unaddressed. Clinical practice is full of bone morphing examples after surgery. The present paper uses the problem of 'flexure neutralization' to scrutinize if this transformation law as inherent part of a Frost-type mechanostat [Frost, 1987] could explain whole-bone adaptation.

Methods

A remodeling cycle has been implemented using a mechanistic scheme from literature [Huiskes, 2000]. It is based on a mechanotransduction scheme in which osteocytes act as strain sensors. The model container is a 3-dimensional 75x75x75 voxel sized cubic mesh with a voxel length of 60µm. All voxels were assigned with individual isotropic elastic parameters, which were set to compact bone mechanical properties (E=15000MPa) to define a starting geometry. Randomly varying axial, bending and torsional forces were applied to the upper surface of the container with the lower surface fixed. Strain energy densities were calculated with Finite Element Analysis (FEA, ANSYS, version 12.1) as input for the transformation scheme.

Results

Starting from a sharply kinked tubular structure after approximately 570 steps of remodeling calculations a quasi stable straight geometry was achieved.

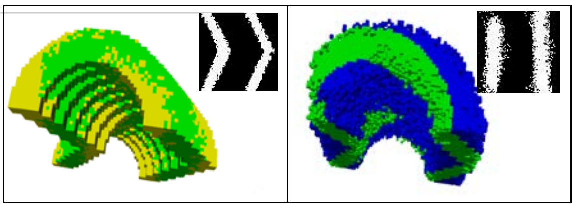

Figure 1: flexure neutralizing drift of a kinked tube (left) to a straight tube (right); yellow shows resorbed bone, blue shows added bone, green is unchanged

Similar results have been achieved starting from a kinked cylindric geomety of a cubic lattice. It has been shown, that the presence of torsional moments along the main axis and the choice of certain parameters for the remodeling scheme play a crucial role for the final geometry. However, our current mechanostat model constantly failed to generate smooth periosteal surfaces.

Discussion

The present in-silico study has shown that a mechanostat scheme based on basic mechanistic principles can engender a shaft-like geometry in response to a loading regime that is typical for a long bone shaft. The Huiskes mechanostat mechanism seems to explain flexure neutralization more elegant than the phenomenologic approach in the work of Frost [Frost, 1990]. On the other hand it remains unclear under what assumptions mechanostat-like transformation could generate smooth periosteal surfaces.

References

Frost,H.M., The Anatom. Rec., 219,1-9 (1987)

Frost,H.M., The Anatom. Rec., 226, 414-422 (1990)

Huiskes,R. *et al*, Letters to Nature, 400:704-706 (2000)