Bone remodelling using the cartesian grid finite element method

O.M. León[1], E. Nadal[1], O.A. González-Estrada[2], J. Gutiérrez-Gil[1], J.M. Navarro-Jiménez[1], J. Albelda[1], J.J. Ródenas[1]

[1] Centro de Investigación en Ingeniería Mecánica (CIIM), Universitat Politècnica de València (España) {osleour, ennaso, jorgugi1, jonaji, jalbelda, jjrodena}@upv.es
[2] GIEMA, Universidad Industrial de Santander, Bucaramanga, Colombia, agonzale@saber.uis.edu.co

ABSTRACT

In order to study the process of bone remodelling, it is crucial to know the mechanical response of the bone tissue to external stresses. Given the significant complexity of the characteristics of biological materials and the Boundary Conditions (BCs), numerical methods are usually applied to obtain the required stress and strain fields in the bone. Generally, classical numerical approaches have two main drawbacks. The first one is the tailor-made generation of finite element meshes which represent the bone geometry, while the second one is related to the highly time-consuming bone segmentation procedures from the diagnosing image.

In this work, the study of a bone remodelling model in three dimensions is proposed through the use of the Cartesian Grid Finite Element Method (cgFEM), which allows the generation of finite element models directly from the diagnosing image, thus simplifying considerably the simulation procedure and favouring its automatization. In the context of iterative meshing with local modifications, the use of structured, geometry-independent meshes with embedded models, is advantageous since they are efficiently generated and since a high fraction of the computed data can be recycled during the assembly of the system of equations.

Regarding bone biomechanics, various remodelling models have been proposed. Wolff [1] observed that the living tissue of the bone adapts to the external stimuli that it suffers, posing a continuous constitutive model that relates tensions and deformations. Frost [2] showed that bone mass reabsorption and generation are regulated by the level of local strains. Later, the damage-based model developed by Doblaré [3] incorporated the *fabric tensor* concept for evaluating the bone anisotropy degree at a certain simulation instant. This last model is considered in the present work.

The results in 2D are similar to those in literature. In 3D, the procedure is applied to a model with initial random distribution of bone densities. Here, a topological distribution of the densities is according to the loads applied, demonstrating the effective simulation of resorption and regeneration phenomena in bone tissue. A second example simulating the bone remodelling process around an immediate-load dental implant also produces satisfactory results.

Keywords: bone remodelling, cgFEM, patient-specific, structured grids

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