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Application of the Cartesian Grid Finite Element Method to image-based bone remodelling process

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ABSTRACT

The bone remodelling is the process by which the bone is reabsorbed, or is regenerated, as a function of the received mechanical stimuli and of different biological factors. This process is carried out by the osteoclasts, which are the cells in charge of the destruction or reabsorption of the old tissue, and by the osteoblasts that synthesize the new tissue. For the study of the phenomenon of bone remodelling, it is necessary to know the mechanical response of the bone tissue against external stresses. Given the complexity of the boundary conditions and characteristics of biological materials, numerical methods are often used to obtain stress and strain fields in this type of problem. This process usually involves the time-consuming bone segmentation procedure from the medical images and the elaboration of finite element mesh that represent the geometry of the bone. In this work the study of a model of remodelling in three dimensions performed by means of Cartesian Grid Finite Element Method (cgFEM) [1] is presented. The use of cgFEM allows to generate a finite element model directly from medical images, i.e. computerized axial tomography (CT), considerably simplifying the analysis process.

Regarding bone biomechanics, different models of bone remodelling have been proposed. Wolff [2] observed that the living tissue of the bone adapts to the external stimuli that it suffers, proposing that the cancellous bone tends to align itself with the main directions of the stresses, posing a continuous constitutive model that relates stresses and strains. Frost [3] indicated that the local strains regulate the bone mass so that, if the strains overpass a threshold, the bone will tend to form, whereas if they are small enough the bone will tend to absorb. In this work we consider the bone remodelling model proposed by Doblaré and García [4], based on damage mechanics, and incorporating the concept of fabric tensor to evaluate the degree of anisotropy of the bone at each time.

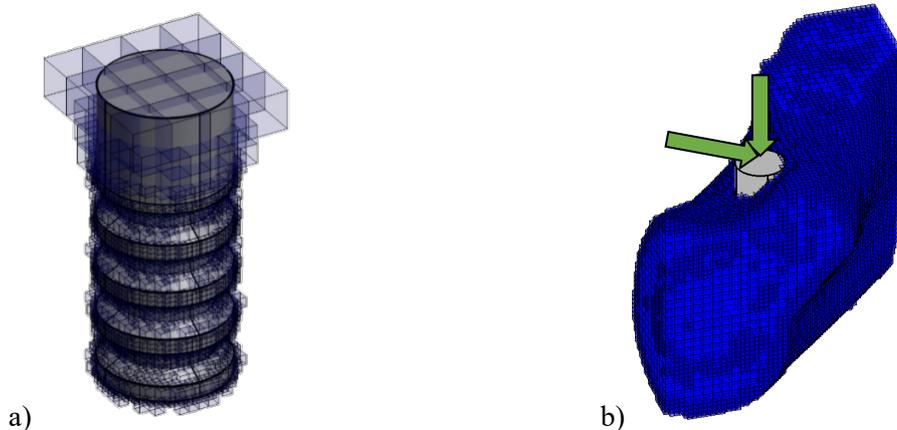


Figure 1: Finite element model of an implant (a) and a mandible (b).

Thanks to the cgFEM technology, to consider the actual medical image, both cortical and trabecular bone, is straightforward. Also, the contact boundary conditions between the implant and the bone are

easily considered. Figure 1a shows the geometry of the implant (a screw) which is meshed with the cgFEM. Figure 1b shows the resulting mesh for a part of a human mandible in which the implant is inserted. Over the top implant face a normal and a tangential force is applied. Figure 2a shows the bone density at the beginning of the remodelling process. You can appreciate the higher density near the boundary, corresponding to the cortical bone, while smaller density in the middle, corresponding to the trabecular bone. After the 100 days, the bone remodelling process yields the bone density shown in Figure 2b, in which the zones that do not transmit any load the bone tends to reabsorb. Additionally, Figure 2c shows that the zones surrounding the implant the bone densifies since new load paths appear after the colocation of the implant.

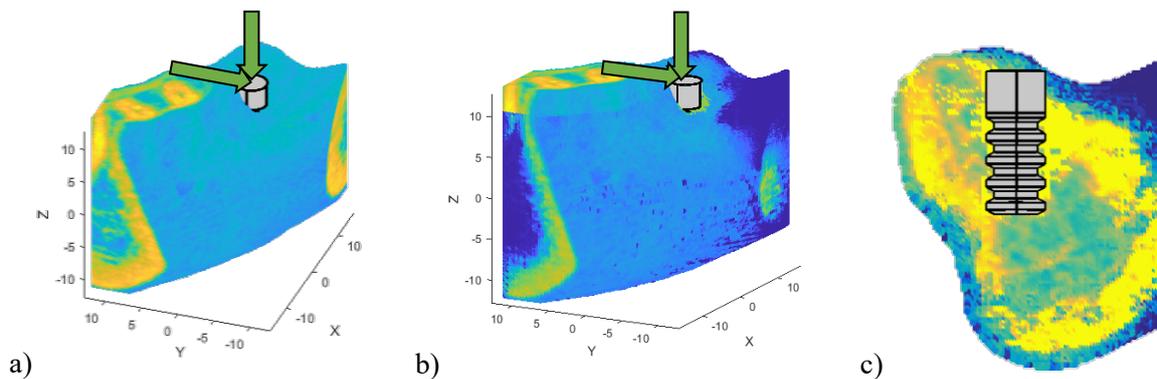


Figure 2: Bone density at the beginning of the remodelling process (a) and at the end of the remodelling process (b). (c) shows a detail at the end of the bone remodelling process near the implant.

To sum up, a model of bone remodelling based on the Cartesian grid Finite Element Method has been developed. The use of Cartesian meshes simplifies the process of segmentation of the medical images and decreases the computational cost. The proposed models show good results for the processes of resorption and regeneration of bone tissue.

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