A contact model with ingrowth control for bone remodelling around cementless stems

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Introduction

The loss of bone on the proximal femur when an implant is present influences the performance of the prosthesis. It can lead to bone fracture, to implant loosening and reduces the amount of bone available for a future revision surgery. Lately, several research works have addressed this problem (e.g. Huiskes and Rietbergen [1]). Usually these models assume the interface bone/stem in contact without friction where the stem is not coated and fully bonded interface if the coat exists.

Actually, this is a correct approach if one considers complete bone ingrowth in the coated zones. However, the bone remodelling after a total hip arthroplasty is an evolutionary process, i. e., in a post operative situation the bone ingrowth does not exists but, if the local mechanical conditions permit, it can appears. Although interface conditions and the bone ingrowth process has been studied in several research works (e.g. Keaveny and Bartel [2]), a method that integrates ingrowth analysis and bone remodelling is hardly found.

The formulation developed in this work addresses the problem of bone remodelling together with the changes in the interface conditions along the process. To develop such model, it will be assumed that trabecular bone is a structure, “optimised” to satisfy several criteria including the local mechanical environment. Thus, one can speculate that the loss of bone around the stem stops when an “optimal” structure is achieved. Motivated by this idea, Fernandes et al. [3] proposed a global optimisation procedure to simulate the process of bone resorption. In later works, the model was applied to an implanted femur (Fernandes et al. [4]) considering bone and stem surfaces to be in contact. In the present work, the model described in [4] is improved. The result is a model able to modify the contact conditions during the remodelling process, depending on the existence of bone ingrowth.

Methods

Bone remodelling model

Trabecular bone is modelled as a porous material with variable relative density and periodic microstructure. Such material is obtained by the repetition of cubic cells with prismatic holes. The equivalent orthotropic elastic properties are computed by the homogenisation method. The optimisation goal is to minimise, with respect to density, a linear combination of the compliance (inverse of structural stiffness) and the metabolic cost to the organism of maintaining bone tissue. The necessary conditions for optimum are derived analytically and solved numerically through a suitable finite element discretisation. At each iteration, the contact conditions are modified based on the stem/bone relative displacement criterion.

The Bone Ingrowth control

In this work, we propose the following procedure to detect bone ingrowth. At an immediate post-operative situation, no bone ingrowth is considered. Thus, the initial conditions are contact with friction if the surface is coated and contact with friction zero otherwise. After each time step the relative displacement is computed. If, at a certain contact node the bone/stem relative displacement is less then a threshold value, the interface condition is set to bonded instead of friction. Consequently, on the coated surface, we have simultaneously regions in contact with friction and bonded zones.

Results

The model is tested on numerical simulations of bone remodelling around cementless stems with different coat lengths to investigate the influence of the coating on the bone remodelling and ingrowth process. Figures 1a) and 1b) present the density distribution after remodelling for a partially coated stem and figures 1c) and 1b) show the ingrowth distribution on coated surface. Red and orange zones indicate ingrowth and blue zones indicate no ingrowth.

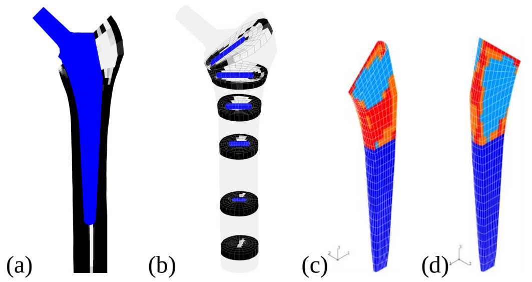

Fig. 1: Density and bone ingrowth distribution

Discussion

In this work a computational model for bone remodelling around cementless stems with ingrowth control was developed. The bone/stem interface is modelled using a contact formulation. The model detects the existence of bone ingrowth, by a relative displacement criterion, and the contact conditions are updated during the process. The model was applied to a three-dimensional finite element model of an implanted femur. Results give us information about the bone remodelling and the distribution of bone ingrowth.

The distribution of bone densities obtained show the loss of bone on proximal femur. These results agree with the loss of bone clinically observed and with computational results presented by others authors that have evolutionary bone remodelling models (Huiskes and Rietbergen [1]). The results of bone ingrowth distribution on the coated surface show that ingrowth does not occur all over the coated surface. In fact, we can observe regions where separation or high relative displacement occurs. Thus, models such the present in this work, which detects the bone ingrowth and allows us to modify the interface conditions depending on it, are useful for analysis of coated stems.

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