AN ENHANCED VERSION OF DOBLARÉ AND GARCÍA'S BONE REMODELLING MODEL

Marlène Mengoni[1, 2], Jean-Philippe Ponthot[1]
[1] *University of Liege, Department of Aerospace and Mechanical Engineering, Belgium;*
[2] *University of Leeds, Institute of Medical and Biological Engineering, United Kingdom*

Introduction

In [Doblaré, 2002], a phenomenological bone remodelling model is proposed, associating the fabric tensor and the bone density to a damage framework. The bone density can vary according to a remodelling rate**Error! Bookmark not defined.** $\dot{r}$, function of two remodelling criteria for formation and resorption conditions, g_f and g_r:

$$\dot{r} = \begin{cases} c_f \frac{g_f}{\rho^{2-5\beta/8}} & \text{if } g_f \geq 0 \\ 0 & \text{otherwise} \\ -c_r \frac{g_r}{\rho^{2-5\beta/8}} & \text{if } g_r \geq 0 \end{cases} \quad (1)$$

The remodelling criteria are evaluated as functions of the distance between a stimulus associated with the strain energy density, $\boldsymbol{J}$, and its homeostatic value, ψ_t^*, in such a way that (ω is the half-width of the lazy-zone):

$$g_f = K_f(\boldsymbol{J}:\boldsymbol{J})^{1/4} - (\psi_t^* + \omega)\rho^{2-5\beta/8} \quad (2)$$

and

$$g_r = \frac{1}{K_r}(\boldsymbol{J}^{-1}:\boldsymbol{J}^{-1})^{1/4} - \frac{1}{(\psi_t^* - \omega)\rho^{2-5\beta/8}} \quad (3)$$

where K_f and K_r are function of the density ρ and have identical dimensions.

Even though this model elegantly proposes a framework to combine the anisotropy, the density, and their evolution, its resorption criterion however is lacking a dimensional consistency with the remodelling rate. Indeed, assuming c_f and c_r have the same dimensions (as in [Doblaré, 2002]), it is clear from (1) that g_f and g_r must have identical dimensions. However, it is also clear from (2) and (3) that they have inverse dimensions.

Methods

We propose an enhancement of the resorption criterion, assuming the evolution of the remodelling tensor is proportional to the strain energy density [Mengoni, 2012]. This gives a new remodelling criterion in resorption:

$$g_r^{corr} = -K_f(\boldsymbol{J}:\boldsymbol{J})^{1/4} + (\psi_t^* - \omega)\rho^{2-5\beta/8} \quad (4)$$

This corrected version of the resorption criterion is, in its isotropic version, producing resorption conditions for the same stress state and keeping the physical properties of the model.

A second enhancement proposed is to define a remodelling rate that has dimensions of a velocity, as initially defined [Beaupre, 1990]:

$$\dot{r} = \begin{cases} c_f \frac{g_f}{\rho^{2-5\beta/8}} & \text{if } g_f \geq 0 \\ 0 & \text{otherwise} \\ -c_r \frac{g_r^{corr}}{\rho^{2-5\beta/8}} & \text{if } g_r^{corr} \geq 0 \end{cases} \quad (5)$$

The impact of these modifications is evaluated reproducing the 2D remodelling analysis of a proximal femur submitted to walking loading, as proposed in [Doblaré, 2002] among others.

Results

Values of the remodelling rate are higher in the enhanced version of the model. Even though resorption and formation happen in the same areas for both versions, their intensities are higher in the present model. Figure 1 shows the bone density after 300 days of remodelling starting from homogeneous conditions.

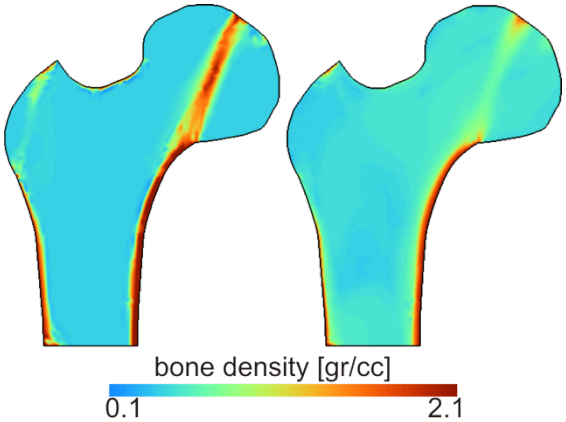

Figure 1: Bone density after 300 remodelling days. Left: Modified model, Right: Original model

Discussion

We proposed enhancements to Doblaré and García's model of internal remodelling. The proposed modifications ensure a dimensional consistency while keeping the physical properties of the original model. The enhanced remodelling rate has higher values than the original, thus producing a faster remodelling.

References

Beaupré *et al*, J Orthop Res, 8:651–661, 1990.
Doblaré *et al*, J Biomech, 35:1-17, 2002.

Mengoni, PhD Thesis (U. Liège), 2012.