STABILITY OF BONE REMODELING MODELS

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Subject-specific finite element models are an extensively used tool for the numerical analysis of the biomechanical behaviour of human bones. However, bone modelling is not an easy task due to the complex behaviour of bone tissue, involving non-homogeneous and anisotropic mechanical properties. Moreover, bone is a living tissue and therefore its microstructure and mechanical properties evolve with time in a known process called bone remodelling. The first phenomenological law that qualitatively described this mechanism is generally known as Wolff's Law. During recent decades, a great number of numerically implemented mathematical laws have been proposed, but most of them have not presented a full analysis of stability and convergence. We revisit the Stanford bone remodeling theory [Garijo et al., 2014] where a novel assumption is proposed, which considers that the reference equilibrium stimulus is changing. One of the main contributions of this work is to modify this assumption, hypothesizing that this reference homeostatic stimulus is not constant, but is locally dependent on the loading history that each local point is effectively supporting.

The linear convergence of the algorithm is deduced under additional regularity conditions. Fully discrete approximations are introduced by using the finite element method and the explicit Euler scheme. Numerical simulations are presented to demonstrate the behavior of the solution. A qualitatively comparison have been done with our modification from the Stanford's model. As outlined by Garijo et al [2014] the number of load cases applied affects significantly to the computational results. Stanford's model obtains the best result in a certain number of days (300) (Figure 1a). As time goes on, the results become less accurate (Figure 1b and c). There is no numerical stability of the model. The modification proposed in this works shows a stabilized bone density distribution (Figure 1d, 1e and 1f). These results clearly show a great improvement in the stability of the solution with the modification proposed for the Stanford's model. Another contribution of this work, independently of initial conditions selected in the model, we obtain the same result.

For that, we can conclude that these modifications improve the convergence of the solution, clearly leading to its numerical stability in the long-term and finally, the independence of the final solution. All these contributions could be obtaining a patient specific model for recreate the density in a bone.

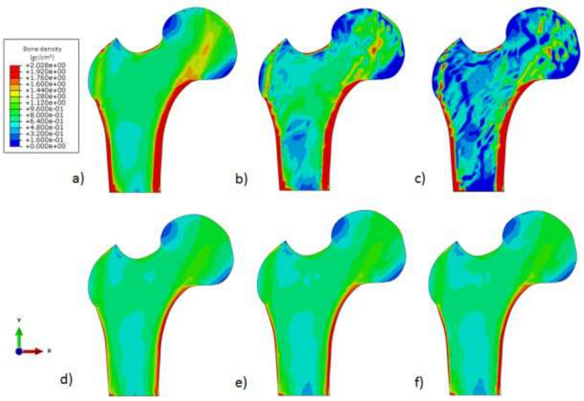

Figure 1: The density distribution resulting from a bone remodeling simulation carried out using the traditional remodeling model (Jacobs1995) for (a) 300 days, (b) 1000 days, and (c) 4000 days; and the modified model for (d) 300 days, (e) 1000 days and (f) 4000 days.

References

N. Garijo, J.R. Fernández, M.A. Pérez, J.M. García-Aznar, Numerical stability and convergence analysis of bone remodeling model, Computer Methods in Applied Mechanics and Engineering, (2014), 271:253-268.