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Research paper

Numerical model of bone remodeling sensitive to loading frequency through a poroelastic behavior and internal fluid movements

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In this article, a phenomenological numerical model of bone remodeling is proposed. This model is based on the poroelasticity theory in order to take into account the effects of fluid movements in bone adaptation. Moreover, the proposed remodeling law is based on the classical 'Stanford' law, enriched in order to take into account the loading frequency, through fluid movements. This coupling is materialized by a quadratic function of Darcy velocity. The numerical model is carried out, using a finite element method, and calibrated using experimental results at macroscopic level, from the literature. First results concern cyclic loadings on a mouse ulna, at different frequencies between 1 Hz and 30 Hz, for a force amplitude of 1.5 N and 2 N. Experimental results exhibit a sensitivity to the loading frequency, with privileged frequency for bone remodeling between 5 Hz and 10 Hz, for the force amplitude of 2 N. For the force amplitude of 1.5 N, no privileged frequencies for bone remodeling are highlighted. This tendency is reproduced by the proposed numerical computations. The model is identified on a single case (one frequency and one force amplitude) and validated on the other ones. The second experimental validation deals with a different loading regime, an internal fluid pressure at 20 Hz on a turkey ulna. The same framework is applied, and the numerical and experimental data are still matching in terms of gain in bone mass density.

1. Introduction

First studies on bone remodeling were based on clinical observations, (Wolff, 1892). The first mathematical law describing this phenomenon, was a relationship between the strain engendered by external forces, and the variation of bone specific mass. Other remodeling laws were developed, in particular the one which will underpin this work, called 'Stanford' law in the following (Beaupré et al., 1990b,a). It describes the same phenomenon, relating this time a

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