BONE REMODELING MODEL OF A BASIC MULTICELLULAR UNIT

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INTRODUCTION

The bone tissue adapts itself to the mechanical and physiological environment and involves cellular processes of mechanotransduction and remodeling. In fact, bone remodeling results from closely coupled resorption and apposition processes of organized cellular units called Basic Multicellular Units (BMUs) which are controlled by local mechanical signals. Recent studies revealed that osteocytes which are the most abundant cells in bone play a fundamental role as mechanosensors in the early stage of bone remodeling [1]. Moreover it has been shown that osteocyte apoptosis induces bone resorption and appears at very high or very low strains level. However mechanotransduction, biological and biochemical processes involved in the resorption/formation coupling are complex and not yet clearly identified.

The idea of the present study is to develop a model to mechanically simulate the resorption/apposition processes of a BMU taking into account high and low strain energy, microcracks, osteocyte apoptosis, fluid flow effects as well as biochemical factors. The present mechanical model is based on thermodynamic approaches following Silva and Ulm [2] resorption model.

METHODS

The present bone remodeling model is applied to one isolated trabeculae of spongy bone considered as a homogenous isotropic and elastic cylinder containing a network of canaliculae with osteocytes. The biochemical activities of the osteoclasts to dissolve bone matrix and the osteoblasts to synthesize collagenous matrix are translated into energetic quantities which transformations are studied using the two thermodynamical principles. During the resorption phase, the dissolution potential of the cell is balanced by the strain energy of the trabeculae and a chemical energy due to the osteocyte apoptosis. During the apposition phase, the chemical potential of the cell to synthesize collagen is balanced by the trabeculae strain energy through the adherent surface and a chemical energy of the factors released during the resorption phase. Two scenarios of bone remodeling are simulated considering a low strain energy which is defined by *understress* conditions and a high strain energy which is defined by *overstress* conditions.

RESULTS AND DISCUSSION

The numerical results show the variation of the final bone volume (after remodeling) normalized by the initial volume as a function of the strain energy normalized by reference strain energy in two stress conditions (*understress* and *overstress*). Figure 1 shows that the final bone volume obtained after remodeling tends to a non zero minima (i.e. for no stress applied; W*=0). Two parameters have been introduced in the model: the coupling parameter α represents the chemical energy of factors and proteins released in the medium during the resorption phase which might stimulate the recruitment and the differentiation of the osteoblasts.

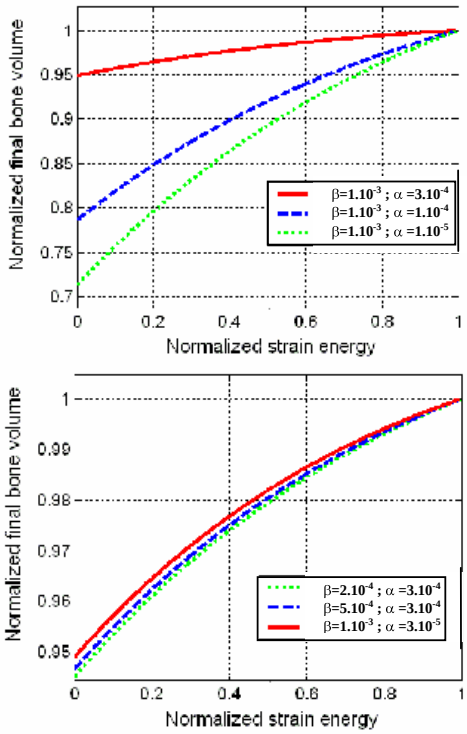

Figure 1: Final bone volume normalized as a function of the applied normalized strain energy in *understress* conditions.

The parameter β represents the mechanical sensibility of the osteoblasts during the apposition phase. It appears that in *understress* conditions, the new bone volume seems to be regulated mainly by chemical factors (the coupling parameter α) because the increase of the mechanical sensibility of the osteoblasts has no effect on the final bone volume (see Figure 1). By contrast, in *overstress* conditions, the numerical results show that increasing β increases the new bone volume more than the coupling parameter α. Since this model could contribute to understanding bone remodeling related to cellular activity and more particularly in pathologic cases (osteoporosis), further studies are needed to validate this model and to identify the parameters introduced in the model.

REFERENCES

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2. Silva E.C., et al. *Proceedings of te 15th ASCE Engineering Mechanics Conf.*, New York, 2002.