FINITE ELEMENT ANALYSIS OF SHOCKWAVE PROPAGATION IN CORTICAL BONE

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INTRODUCTION

Osteoporosis on Earth and disuse osteopenia associated with prolonged exposure to microgravity show parallels including loss of bone mass and changes in cellular remodeling activity. Knothe and colleagues [1] have proposed the use of extracorporeal shock waves (ESW) as a means to combat bone loss. Results from in vitro pilot experiments have demonstrated the feasibility of creating microcracks in cortical bone similar to those occurring during physiological loading [1]. Based on the global hypothesis that microdamage acts as a trigger for the onset of remodeling by altering fluid flow and cell signaling, we propose that controlled application of ESW to bone tissue stimulates bone turnover. In order to better understand the therapeutic effect of ESW and to effectively develop this as a potential clinical application, the actual mechanics of the wave propagation and its interaction with local microstructure were analyzed using finite element models.

METHODS

The finite element analysis was run on the implicit solver of Abaqus 6.4 (HKS Inc., Pawtucket, RI). The basic shape for the model was a prismatic beam with isotropic, homogeneous material properties (Fig. 1A). Structural characteristics corresponding to the micro-architectural features of cortical bone tissue, i.e. lamellae, osteons with Haversian canal, and lacunar spaces, were subsequently included in distinct models (Fig. 1C-D). Comparable to the technical specifications of the lithotripter, the shockwave pulse was implemented as a haversine wave with high compressive amplitude (50-100Mpa), quick build-up time and short pulse width (1microsec). Parametric studies were carried out for different material and wave properties [2,3]. The effect on wave propagation along the beam due to changes in stiffness, density, pulse width and amplitude, as well as due to lamellar thickness and the presence of cavities was evaluated.

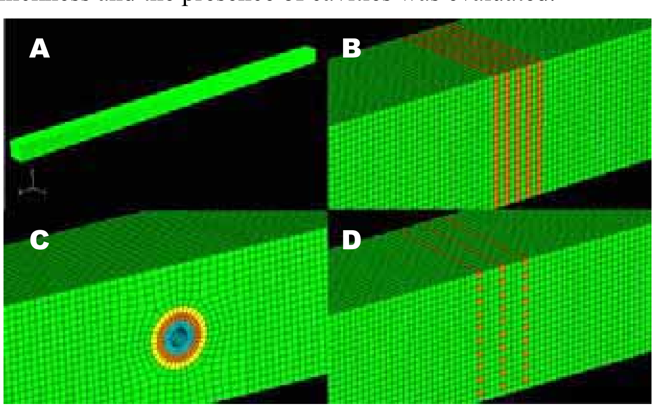

Figure 1: Basic model (A) and three modeled scenarios: lamellae (B), osteon (C) and lacunae (D).

RESULTS AND DISCUSSION

Noticeable changes in stress distribution of the propagating shockwave occurred when interfaces were modeled with very low stiffness (e.g. lacunae and Haversian canals) (Fig.2C-D). In these cases, the stress transmitted through the interface rapidly decreased with increasing interface thickness. Furthermore, in front of those inhomogeneities stress quickly changed from maximal compression to maximal tension due to reflection. When the change in stiffness was less than an order of magnitude, the interface had little effect on the traveling wave and, thus, the stress was not altered considerably.

CONCLUSIONS

In this study a model was designed that had the necessary spatial resolution for the characterization of bone properties like osteons, lamellae and lacunae, and at the same time could adequately represent the temporal resolution of a real shock wave pulse. More insight into the propagation pattern and stress distribution of a shock wave traveling in an isotropic, though inhomogeneous material was obtained. The possible effects of various interfaces were assessed. The next step will be the implementation of non-linear material behavior and algorithms incorporating the effect of damage.

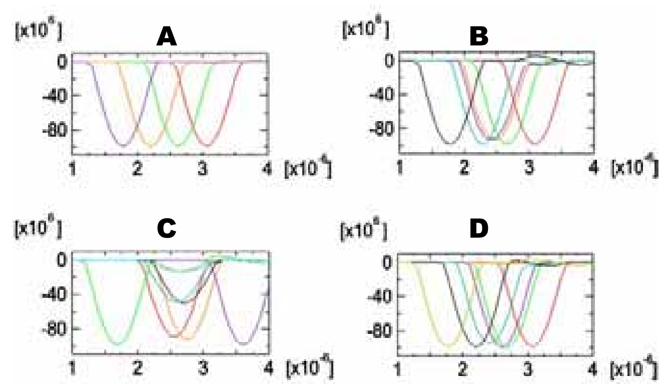

Figure 2: Stress distribution at different locations along the beam, corresponding to the modeled scenarios of Fig.1 (x-axis: time in sec, y-axis: stress in Pa).

REFERENCES

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