COMPARISON OF MECHANO-REGULATION PARAMETERS FOR TISSUE DIFFERENTIATION DURING FRACTURE HEALING

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INTRODUCTION

The majority of long bone fractures heal through indirect (secondary) fracture healing, similar to the process of endochondral ossification. This implies a process of tissue differentiation, which is known to be sensitive to the local mechanical environment. Several authors have proposed mechano-regulation theories, based on different mechanical stimuli. The objective for the present study was to compare the mechano-regulation theories published in the literature to each other, and to investigate what the contributions of the separate stimuli assumed in these theories contribute, using the same computational model.

METHODS

An osteotomy of a long bone was analyzed using an axisymmetric finite element model (ABAQUS). To simulate fracture healing, the biophysical stimuli calculated from the FEA were used to predict new element material properties according to mechano-regulation rules (MATLAB). Each iteration simulated one day. Initially, the callus was assumed to consist of granulation tissue into which precursor cells could migrate. The precursor cells originated in the soft tissue external to the callus, the periosteum and the marrow. All tissues were modeled as linear poroelastic and the material properties were similar to those used by Lacroix *et al.* (2002). Previous studies have applied a daily constant load, which was set to 300 N (1 Hz). To more realistically simulate fracture healing, an increasing load, dependent on the interfragmentary motion in the gap (3mm) was also investigated.

The mechano-regulation theories explored with this model were the combined effects of deviatoric strain (γ_o) and fluid velocity (υ_f) (Lacroix *et al.,* 2002) and the effects of principal tensile strain (ε_1) and hydrostatic pressure (p_h) (Carter *et al.,* 1998 and Claes *et al.*, 1999). Then, the effects of deviatoric strain, hydrostatic pressure and fluid velocity alone was simulated separately.

RESULTS

With constant daily loading, the mechano-regulation theories of Carter, Claes and Lacroix all similarly stimulated the course of normal fracture healing, (i) intramembranous bone formation, (ii) endochondral ossification, and finally (iii) bone growth towards the gap with initial lateral osseous bridge. Resorption of the callus was only stimulated by the theory of Lacroix. The speed of healing was most sensitive to the cell diffusion. In addition, small differences could be seen between the models, where the theories of Carter and Claes were faster than Lacroix.

Fracture healing as function of only deviatoric strain $(\gamma)_o$ also simulated the same features of normal fracture healing. Similar to the other theories, bone growth and bridging occurred in the intramedullary canal. However, this bone eventually resorbed. Decrease in interfragmentary displacement was slowest with that simulated by γ_o but similar in character over time. Fracture healing as a function of only hydrostatic pressure (p_h) or fluid velocity (υ_f) did not correctly simulate healing. With υ_f, isolated gap bridging occurred and with p_h, the external callus experienced transient softening.

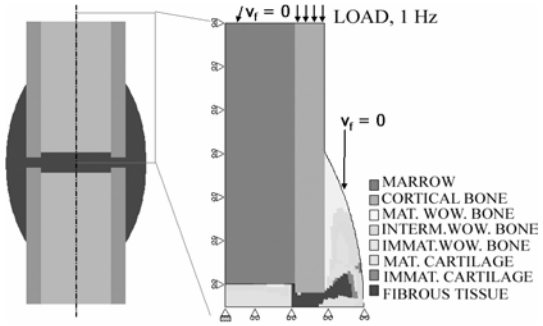

Figure1: Tissue type in the healing callus at day 10 (γ_o model)

DISCUSSION

The model allowed direct comparison of different mechano-regulation theories. Comparison between the constant and the gradually increasing load are still under investigation.

The proposed mechano-regulation theories are all composed of a volumetric and a deviatoric component of loading/deformation. Therefore it is not unexpected that they simulate fracture healing. The simulation only as a function of deviatoric strain (γ_o) only, was surprisingly accurate. Since volumetric parameters (p_h or υ_f) did not simulate healing, it suggests that deviatoric strain may be the most significant individual mechanical parameter in tissue differentiation.

REFERENCES

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