IS THE CALLUS SHAPE AN OPTIMAL RESPONSE TO A MECHANOBIOLOGICAL STIMULUS

F. Ribeiro[1], P.R. Fernandes[1], J. Folgado[1], J.M. García-Aznar[2]

[1] IDMEC-Instituto Superior Técnico, Tecnical University of Lisbon, Portugal; [2]I3A, University of Zaragoza, Spain

Introduction

The secondary bone healing is typically described in four stages [Schindeler, 2008]: the hematoma, the soft callus formation, the hard callus formation and the remodeling stage.

To the best of our knowledge, it seems that almost all the models set a fixed geometry and focus on mechanical stimuli that control cell and tissue differentiation. Yet, it is sometimes neglected the influence of the callus shape and geometry into the stimuli distribution and thus in all the cells response [García-Aznar, 2007]. The aim of this paper is therefore to identify the stimuli that are most likely to regulate the callus shape during the healing process.

Methods

Six objective functions were defined. Table-1 summarizes the stimulus used in each function as well as the domain in which they are defined. Where u is the displacement, ψ is the second invariant of the deviatoric strain tensor, ψ_{ref} is a chosen reference stimulus, and ψ_{lim} is a reference stimulus found in the literature [García-Aznar, 2007] and c_{ref} is a chosen reference concentration for a generic inflammation factor. Finally PB stands for periosteal border.

The stimulus was computed using a finite element model of a fractured bone. Each of the objective function was minimized using the steepest descent optimization method. In each iteration, the set of reference points on the periosteum is updated in order to optimize the callus shape.

Function	Stimulus	Domain
f_1	u	callus
f_2	Ψ	callus
f_3	Ψ	gap
f_4	Ψ_{ref}	PB
f_5	Ψ_{lim}	PB
f_6	C_{ref}	PB

Table 1 - stimuli and domain for the objective functions

Results

The results obtained are presented in Fig. 1. Each subfigure corresponds to the optimization of an objective function.

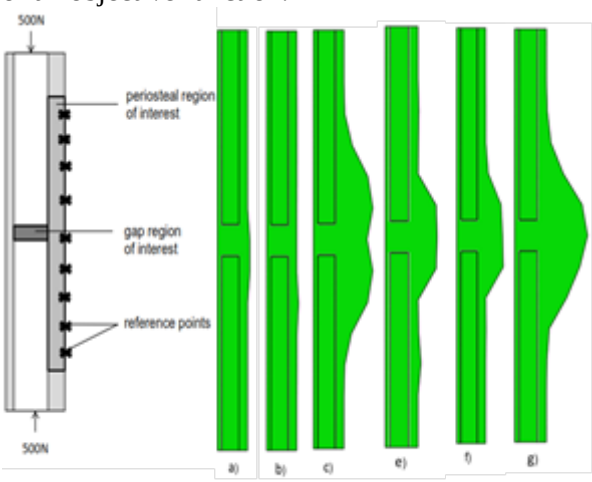

Figure 1 – Schematic of the problem and results found

Discussion

Fig.1a and Fig.1b result from objective functions that have different stimuli but are defined on the same domain. Therefore we can suppose that the periosteal does not have much influence upon the callus shape.

In Fig.1c, we would expect one single hump instead of two in the callus. It looks like two fronts from both sides of the gap meet. Looking at some histological cuts in the literature [Claes, 1999], this effect is recurrent.

Fig.1e and Fig.1f develop the necessary shape to have the reference stimulus value along the border.

We can say that the callus shape seems in fact to be an optimal response to a stimulus using a mechanical stimulus (Fig.1c). Yet, the biological model also looks promising.

References

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