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A MECHANO-BIOLOGICAL MODEL TO PREDICT THE ROLE OF IMPLANT SURFACES IN THE PERIPROSTHETIC HEALING

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Introduction

Conditions influencing bone growth in the early post-operative period include the surgical technique, mechanical [Prendergast, 1997] and biochemical factors [Bailón-Plaza, 2001]. Low performances of implant fixation were generally associated with a low mineralization or a strong heterogeneous distribution of bony structure in the new-formed surrounding tissue and the physico-chemical properties of the implant surface might pay a significant role. We previously developed a mechanobiological model of healing coupling porous media mechanics to biomathematics [Ambard, 2006]. To go further, we hypothesized that such mathematical model could be completed to investigate the role of implant surface in cell proliferation, migration, and adhesion. The application concerned our stable canine implant [Vestermark, 2004].

Methods

The coupling of porous media mechanics and biomathematic allowed the diffusive-convective-reactive governing equations (1) to be derived; *L, C, D, Ω* respectively were the local variation, the convection, the diffusion, and the source terms.

$$L\,\partial x/\partial t + C\ \mathrm{grad}(x) = D\ \Delta(x) + \Omega \qquad (1)$$

Output measures were the structural (or mineralized fraction) ϕ_s, the fluid fraction ϕ_f, the growth factor concentration C_g (TGF-β) and the osteoblast concentration C_o. Structural porosity, fluid flow and growth factors conditionned the cellular behavior (proliferation, chemotactic & haptotactic migrations, mineral fraction aposition). The cell adhesion influenced the motility through the cell diffusion coefficient D_o dependant upon the substrate (bone or implant). The growth factor retention into the initial gap was modelled by a local diffusion coefficient. The source of growth factors involved the osteoblast concentration C_o, the growth factor concentration C_g to take into account the autocrine and paracrine modes of TGF-β, and α_g dependant upon the osteoblast localization (bone or implant). The model of cell proliferation was similar (equ.3); N_o being the proliferation threshold, C_0 the initial growth factor concentration.

$$\Omega_g = \alpha_g (1-\phi_s)^{1.5} C_o^{\,0.5} C_g \qquad (2)$$

$$\Omega_o = \alpha_o (1-\phi_s)^2 C_o [N_o - (1-\phi_s) C_o](C_g - C_0) \qquad (3)$$

The PMMA implant [Vestermark, 2004] was the reference and we compared with two other surface treatments: acid-etched and coarse grit blasted acid-etched with RGDS peptide. Material properties are given in Table 1 [Dee, 1999], [Rausch, 2007].

	Acid	C-RGDS	PMMA
α_g (e^{-9}cell$^{-0.5}$/s)	5.22	10.1	2.82
D_o (e^{-7}mm^2/s)	1.75	1.45	1.75

Table 1: Material properties

Results

The implant healing showed a polar symmetry and we plotted in Figure 1 the radial distribution of mineralized fraction from the implant surface toward the surrounding bone after 4 weeks. We observed the influence of implant surface properties since mineralized fraction increased from 62% for the PMMA implant to 85% for the C-RGD surface.

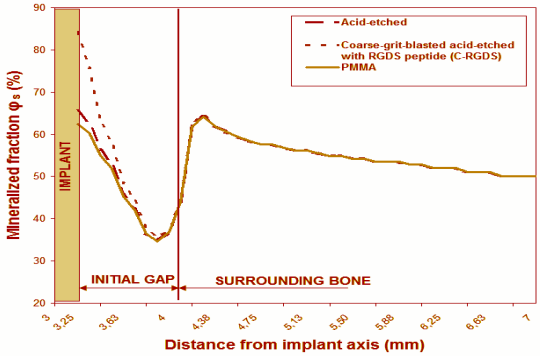

Figure 1: Distribution of mineralized fraction

Discussion

The TGF-β synthesis coefficient α_g and cell diffusion coefficient D_o, were two main parameters that allowed the mechanobiological role of the implant surface to be predicted in time and space. The decrease of cell diffusion (D_o) and the increase of growth factor synthesis (α_g) improved the bone formation. We also noticed that it was decreasing for the highest value of the litterature, probably because of a too rapid accumulation of cells in the vicinity of the implant and an early haptotactic migration towards the surrounding bone where the porosity gradient stayed important.

References

Ambard *et al*, E.JMech Sol/A, 25:927-937, 2006.
Bailón-Plaza *et al*, J Theo Biol, 212:191-209, 2001.
Dee KC *et al*, Biomaterials, 20:221-227, 1999.
Prendergast *et al*, Clin Biomech 12:343-366, 1997.
Rausch-Fan *et al*, Dent Mater, in press, 2007.
Vestermark *et al*, J Orth. Res. 22(3):647-52, 2004.