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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; \( L, C, D, \Omega \) respectively were the local variation, the convection, the diffusion, and the source terms. \( L \frac{\partial x}{\partial t} + C \frac{\partial x}{\partial t} = D \Delta x + \Omega \) (1)

Output measures were the structural (or mineralized fraction) \( \phi_s \), the fluid fraction \( \phi_f \), the growth factor concentration \( C_g \) (TGF-\( \beta \)) 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-\( \beta \), and \( \alpha_g \) dependant upon the osteoblast localization (bone or implant). The model of cell proliferation was similar (equ.3); \( N_o \) being the proliferation threshold, \( C_o \) the initial growth factor concentration.

\[
\Omega_g = \alpha_g (1-\phi_f)^{1.5} C_o^{0.5} C_g
\]

\[
\Omega_o = \alpha_o (1-\phi_i)^2 C_o [N_o (1-\phi_f) C_o] C_g - C_o
\]

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].

<table>
<thead>
<tr>
<th>Material</th>
<th>Acid Etch</th>
<th>C-RGDS</th>
<th>PMMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \omega_\phi ) (cell/mm²/s)</td>
<td>5.22</td>
<td>10.1</td>
<td>2.82</td>
</tr>
<tr>
<td>( D_o ) (mm²/s)</td>
<td>1.75</td>
<td>1.45</td>
<td>1.75</td>
</tr>
</tbody>
</table>

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.

Discussion

The TGF-\( \beta \) synthesis coefficient \( \alpha_g \) 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 (\( \alpha_g \)) 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