Journal of Biomechanics 44 (2011) 1980–1986

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Wave front migration of endothelial cells in a bone-implant interface

Georges Khalil [a], Sylvie Lorthois [a], Manuel Marcoux [a], Pierre Mansat [a,b], Pascal Swider [a,*]

[a] IMFT UMR CNRS 5502, 1 Allées Professeur Camille Soula, 31400 Toulouse, France
[b] Orthopaedic Surgery, Toulouse University Hospital, University of Toulouse, France

ARTICLE INFO

Article history:
Accepted 5 May 2011

Keywords:
Implant fixation
Angiogenesis
Endothelial cells
Growth factor
Reactive transport

ABSTRACT

The neo-vascularization of the host site is crucial for the primary fixation and the long-term stability of the bone-implant interface. Our aim was to investigate the progression of endothelial cell population in the first weeks of healing. We proposed a theoretical reactive model to study the role of initial conditions, random motility, haptotaxis and chemotaxis in interactions with fibronectin factors and transforming angiogenic factors. The application of governing equations concerned a canine experimental implant and numerical experiments based upon statistical designs of experiments supported the discussion.

We found that chemotaxis due to transforming angiogenic factors was attracting endothelial cells present into the host bone. Haptotaxis conditioned by fibronectin factors favored cells adhesion to the host bone. The combination of diffusive and reactive effects nourished the wave front migration of endothelial cells from the host bone towards the implant. Angiogenesis goes together with new-formed bone formation in clinics, so the similarity of distribution patterns of mineralized tissue observed in-vivo and the spatio-temporal concentration of endothelial cells predicted by the model, tended to support the reliability of our theoretical approach.

1. Introduction

The periprosthetic healing is an intramembranous process, whose outcome is primarily dependent upon the surgical technique (Hahn et al., 1998). Clinically, it is observed that the neo-vascularization of the site plays a key-role in bone tissue formation (Street et al., 2002; Carano and Filvaroff, 2003; Unger et al., 2007) and this evolving process is the consequence of complex mechanobiological events. It is observed that the first days of healing are of prime importance for the survival of the implant fixation.

Endothelial cells are the primary cells involved in angiogenesis. They participate in the construction of the microvasculature, which provides oxygen and nutrients supply and waste elimination. They also contribute to the tissue response by releasing pro-inflammatory factors and by expressing osteoblast adhesion molecules (Peters et al., 2003).

Transforming angiogenic factors (*TAF*) are secreted during the acute inflammatory response. They diffuse and form gradients of growth factors, which initiate chemotactic active migrations of endothelial cells (Terranova et al., 1985; Folkman and Klagsbrun, 1987; Relf et al., 1997; Friedl et al., 1998; Kellar et al., 2001). Major growth factors involved are vascular endothelial growth factors, acidic and basic fibroblast growth factors and angiogenin (Sholley et al., 1984; Terranova et al., 1985; Paweletz and Knierim, 1989; Stokes et al., 1990, 1991; Anderson and Chaplain, 1998; Unger et al., 2007).

The haptotactic response due to adhesion sites and porosity gradients is a consequence of cell interactions with the extracellular matrix. In particular, fibronectin factors (*FF*), which are major component of the matrix (Bowersox and Sorgente, 1982; Quigley et al., 1983; Maheshwari and Lauffenburger, 1998), are particularly implied in this process. It is known that endothelial cells synthesize and secrete *FF* (Birdwell et al., 1978; Jaffee and Mosher, 1978; Macarak et al., 1978; Rieder et al., 1987; Sawada et al., 1987; Bicknell and Harris, 1997; Anderson and Chaplain, 1998; Harrington et al., 2006). This non-diffusive molecule enhances cells adhesion via integrins (Schor et al., 1981; Alessandri et al., 1986; Johansson et al., 1987; Hynes, 1990; Alberts et al., 1994).

Theoretical and numerical models could potentially help interpret complex events associated with angiogenesis. Models of vasculature formation have been proposed for several physiological applications amongst which tumor angiogenesis was a pioneering application (Anderson and Chaplain, 1998; Harrington et al., 2006; McDougall et al., 2006). Other relevant approaches concerned embryo and midbrain morphogenesis (Al-Kilani et al., 2008) and tissue differentiation (Checa and Prendergast, 2009; Geris et al., 2010).

* Corresponding author. Tel.: +33 561 49 79 44; fax: +33 561 49 67 45.
E-mail address: swider@cict.fr (P. Swider).

0021-9290/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jbiomech.2011.05.008