Designing Nanostructured Surfaces for Enhanced Biocompatibility

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The importance of electrostatic and steric complementarity is well-established in protein-protein interactions in forming the known protein complexes. We are proposing a phenomenological concept based on electrostatic and steric complementarity that may explain the enhanced adhesion of cells to the engineered nanostructured surfaces compared to conventional smooth surfaces.

Orthopaedic implants have used various coatings, such as hydroxyapatite (HA), to encourage osseointegration [1]. However, concerns have been raised about the bioabsorption of the HA layer, the mechanical strength of the HA layer [1, 2] and the HA layer debonding from the metal implant [2, 3]. We report the adhesion and growth of bone marrow stromal cells on the surface of nanocrystalline cubic zirconia [4] films. Cell attachment both *in vivo* and *in vitro* is usually mediated by known adhesive proteins. The absorption of proteins such as fibronectin and vitronectin is a key factor in cell adhesion and bone formation at an implant surface [5]. The role of wettability, charge, and polarity as well as the topology of the surface has been studied in recent years without the emergence of a comprehensive model [5]. The ability of the implant surface to adsorb these proteins determines its aptitude to support cell adhesion and spreading and its biocompatibility [5].

Materials and Methods: We designed and produced ceramic [5] coatings via an ion beam assisted deposition (IBAD) with spatial dispersion (roughness) comparable to the size of proteins (2-20nm). Our ceramic coatings exhibit high hardness (16 GPa) [4] and possess almost a zero contact angles with water and serum (see Figure 1) and excellent adhesion to any substrate. Adhesion and proliferation experiments performed with a bona fide MSC cell line (OMA-AD) on the nano-structured coatings (see Figure 2). OMA-AD is a cloned bone marrow stromal cell line from C57Bl/6 mice.

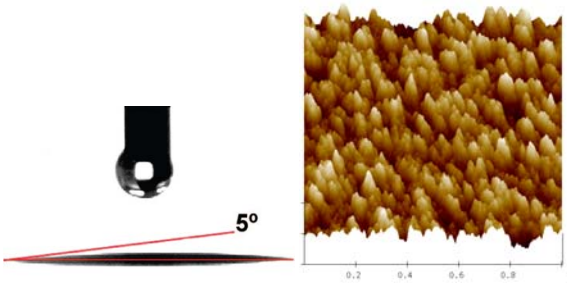

Figure 1. (a) The contact angle showing for a 0.25 µL water droplet on a nanocrystalline cubic ZrO_2 film on Si. (b) AFM image of same sample with Rms of 5.1 nm.

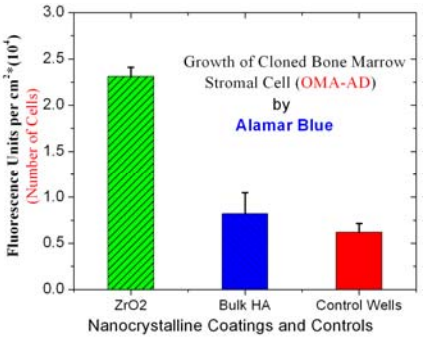

Figure 2. Growth of OMA-AD (as determined by AlamarBlue Assay) on nanocrystalline hydrophilic coatings of cubic zirconia coatings produced by IBAD processes compared with bulk HA and culture plates. The amount of fluorescence produced is directly proportional to the number of viable cells.

Results and Discussion: Our experimental results of the adhesion and proliferation of osteoblast-like stromal cells from mouse bone marrow indicate that our nanostructured coatings were three to five times better than growing on HA and orthopaedic grades of titanium and CoCr. Our phenomenological concept based on the steric and electrostatic complementarity considered for adhesive proteins immobilization on the substrate surface may explain enhanced adhesion of cells to the engineered nanostructured surfaces compared to conventional smooth surfaces. Furthermore, our theoretical calculations and quantum-mechanical modeling clearly indicate that the spatial electric potential variation across our designed ceramic surfaces can be complementary to the electrostatic potential variation of proteins such as fibronectin, promoting increased absorption on these surfaces. Therefore, an increase in the concentration of adhesive proteins on the designed surfaces results in the enhancement of the focal adhesion of cells.

Summary This paper presents the adhesion and proliferation of osteoblast-like cells on micro- and nano-structured surfaces and provides phenomenological concept describing the mechanism responsible for the enhancement of cell adhesion on nanostructured ceramic and metallic surfaces compared with orthopaedic materials.

1. A. El-Ghannam, *Expert Review Medical Devices* 2005 2, 87.
2. B.D. Ratner, *Journal of Dental Education* 2001 65, 1340.
3. O. Reikeras et al, *Acta Orthop Scand.* 2002 73, 104.
4. Namavar F, et al. *Nano Letters* 2008 8, 988-996
5. Wilson C, et al. *Tissue Engineering*. 2005, 11: 1-18