

THESIS FOR DEGREE OF DOCTOR OF PHILOSOPHY IN CHEMISTRY

Integrated Biomechanical, Electronic and Topographic Characterization of Titanium Dental Implants

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ABSTRACT

Titanium dental implants are medical devices used to restore the function entailed with the loss of one or several teeth. To obtain successful function over long periods, the dental implants must be sufficiently anchored in the bone to withstand the forces induced by for example chewing. Two important factors for obtaining high anchorage strength are *i*) the chemical composition of the material and *ii*) the implant design at all length scales. Topographical features on different length scales induce for example nucleation sites for collagen and minerals, cell attachment and biomechanical stimulation necessary to prevent bone resorption and eventually to gain bone.

The design of nucleation sites at the titanium surface to stimulate bone growth is at the heart of the project presented in this thesis. The aim of the work is to in detail characterize the implant surface and design chemically as well as topographically modified surfaces by complementary experimental studies including electrochemical characterization and biomechanical models. The present thesis is based on three main topics of importance for dental implants: *i*) Surface topography measured with scanning electron microscopy and atomic force microscopy, *ii*) Biomechanical modelling and *iii*) Electronic properties of the surface oxide film investigated using impedance spectroscopy and cyclic voltammetry.

Theoretical finite element studies have shown that the micro-topography of a surface can be designed to induce optimal biomechanical stimulation for bone formation. However, currently used topographical characterization methods for describing dental implant surfaces are insufficient to characterize the topography in the required detail to design such surfaces. In the present thesis, a method to investigate and describe the micro- to nanosized surface topographies is presented. In this method, complementary analysis techniques are used in combination with overlapping analysis areas and data filtering in order to obtain information from surface features in a wide range of length scales. Theoretical models have also been developed with the aim of evaluating the ability of micro- and nanoscaled surface features to induce retention strength with bone. By combining the characterization method and the theoretical models, an integrated characterization method is presented which can be used to design biomechanically optimized implant surfaces with suitable surface topography.

Various modification techniques are used to alter the surface topography and as a secondary effect, the electronic properties of the oxide film will be altered. The effects on the biological response induced by changes in topography and electronic properties separately are therefore difficult to distinguish. The present thesis includes a study where the electronic properties of the surface oxide film were deliberately changed without significant changes in surface topography. The results show that the electronic properties of the oxide film have larger effects on the cellular attachment and apatite nucleation than a small change in topography and that a less insulating oxide film is preferable for titanium dental implants.

The knowledge obtained from the biomechanical models and the electronic investigation was used to design well-characterized nanostructured surfaces created by coating titanium discs with titanium dioxide nanoparticles of different morphology and size. The bioactivity of the coated samples was evaluated by apatite formation and the results show that the coated samples induce earlier apatite nucleation and form thicker apatite layers than the uncoated reference.

The results obtained and presented in this thesis suggest that dental implants should have roughness at different length scales in combination with formation of a thin defect rich oxide. Such an implant is still to be designed and tested under realistic conditions.

Keywords: Surface roughness parameters, 3D-SEM, AFM, Interfacial shear strength, Impedance spectroscopy, Cyclic voltammetry, SBF, MG-63, TiO₂ nanoparticles.

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