Hydroxyapatite formed on titanium via a self-assembled monolayer and its *in-vitro* behaviour

by

DAPENG LIU

School of Chemical Engineering
The University of Adelaide

A thesis submitted for the degree of Master of Engineering Science

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

Signed:

Date:

Summary

Hydroxyapatite (HA) coatings are widely used on metal implant devices to improve biocompatibility, enhance bonding strength and to shorten bonding aging between the implant and natural bones. Current coating methods share a common drawback: coatings produced by these processes are not crystalline and further heat treatment must be performed at high temperature (700 ^{o}C). Unfortunately, this treatment often reduces the bonding strength between the coating layer and the metal substrates and may cause chemical degradation of the HA.

Recently, a biomimetic coating method has been developed. The strategy adopted in this method is to induce formation of the HA layer by coating implant surfaces with biologically inspired functional groups. This attempts to simulate the natural mineralization process occurring in the human body and it is hoped that the low crystallinity problem may be overcome. Unfortunately, industrial-scale production is not attractive due to the slow growth rate of the crystalline layer. Several weeks are required to produce a detectable thickness of HA and the deposited layer's *in-vivo* performance has not been quantified. As a consequence, further studies elucidating the key factors influencing formation of the HA layers and its *in-vivo* performance are desirable.

In this study, self-assembled monolayers (SAM layers) with different functional groups were produced on titanium substrates and characterized. The titanium substrates were immersed in simulated body fluid (SBF) to synthesize HA coatings. After measuring the chemical compositions, crystallinity, morphology and growth rates of those coatings, the optimal SAM for HA formation was determined. In addition, the influences of key variables such as temperature, pH, ionic concentrations and functional groups on HA formation were investigated. The goal of this work was to accelerate the growth of the HA coatings for industrial scale production. Finally, human bone cells behaviors on HA coated titanium were observed to confirm an improvement in the biocompatibility and bioconductivity.

It was found that SAMs significantly enhanced the formation of HA coatings on titanium surface. The optimum functional group for the SAM was –COOH. This functional group produced the fastest rate of formation and a HA coating with morphological attributes and crystallinity most like natural bone. Significant factors

affecting HA formation on –COOH SAM were temperature, calcium concentration and Ca/P ratio in SBF. Significantly, it was discovered that higher temperatures and calcium concentration in SBF substantially increased rate of growth of the HA coating whilst appearing not to adversely affect crystallinity. This could reduce time for producing SAM induced HA coatings on titanium implants from a month to a week. Finally, the HA coating formed at 37 ^{o}C on –COOH SAM substantially enhanced the growth of human bone cells on the titanium surface.

Acknowledgments

Many individuals and several organizations have contributed to this project. I would like to acknowledge my supervisors: Dr. Chris Colby, A/Prof. Brian O'Neill, Dr. Yung Ngothai and Prof. Peter Majewski (IWRI, Uni. SA) for their helpful guidance and kind encouragement. Their significant efforts in this project are highly appreciated and I will never forget their help. I am also grateful to the staff and students in the School of Chemical Engineering, The University of Adelaide. Their friendship, assistance and encouragement lightened the heavy load of postgraduate studies.

I wish to thank Prof. Majewski for providing experimental facilities, chemicals and his technical guidance on SAMs and formation of HA coatings. I would also like to acknowledge Dr. Gerald Atkins (IMVS) for providing key background information and the use of his laboratory to perform the "human bone-cell culture" experiment.

Last but not least, I am grateful to my parents for their financial support during my postgraduate studies and my girl friend, Wenzhuo, for her love and daily life care.

Publications

D. P. Liu, P. Majewski, B. K. O'Neill, Y. Ngothai , C. B. Colby, Performance of different functional groups for HA coating of Ti implants using SAMs, J. Biomed. Mater. Res. (Part A). (Submitted)

Table of Contents

List of Figures

List of Tables