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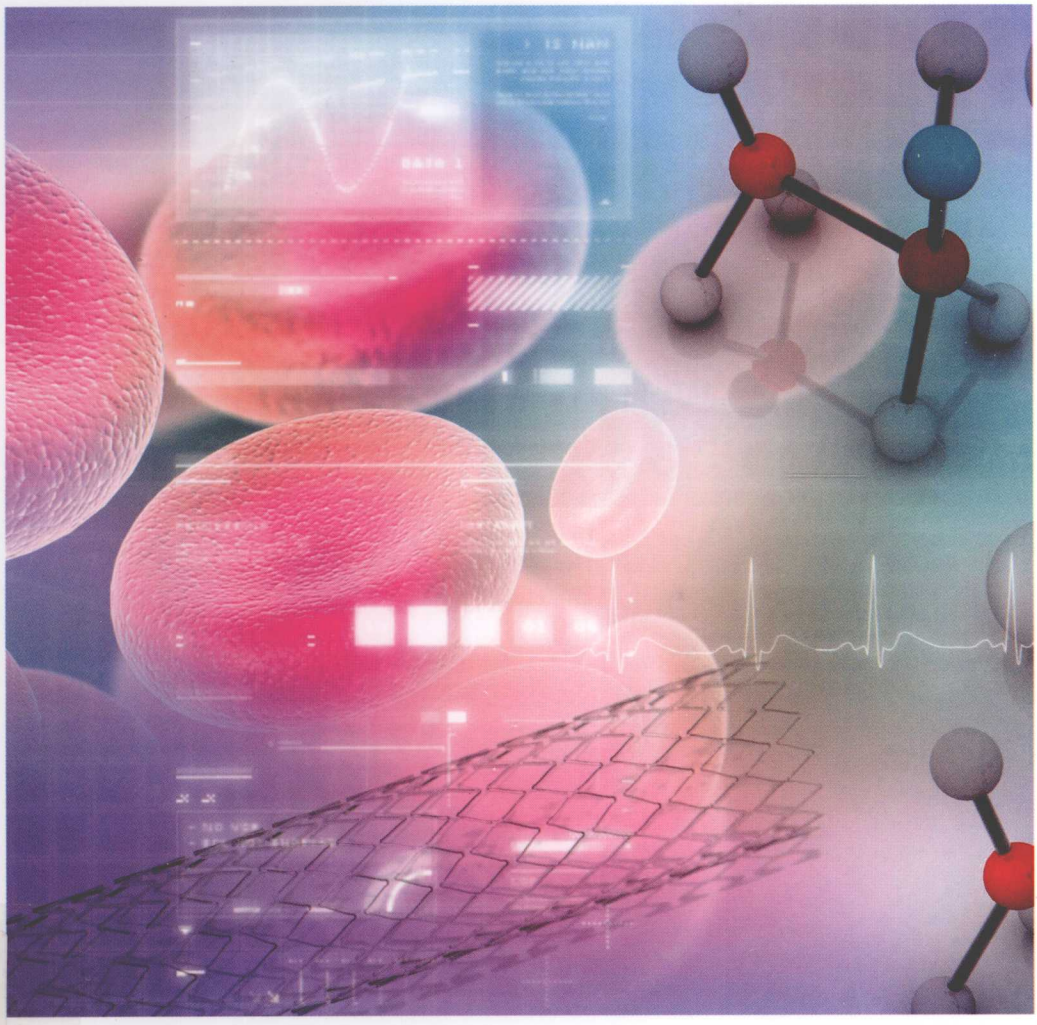
Edited by Syed A.M. Tofail

Biological Interactions with Surface Charge in Biomaterials



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Biological Interactions with Surface Charged Biomaterials

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Preface

Similar to many other objects, tools and devices that we use on a day-to-day basis, electrical charge can be present at the surface of medical devices, many of which are insulators. Even for the devices or materials that are not insulators semi-conducting and insulating properties of the top surface may still produce surface charge.

Electrostatic interactions between a solid surface and a biological species have long been considered to be a contributing factor to the adhesion of biological species on the given solid surface. Despite this, electrical behaviour and surface charge are not currently considered important in the design of mainstream biomedical devices. There are problems such as encrustation or plaque formation that often compromise the long-term performances of indwelling medical devices. Knowledge of the surface charge in biomaterials is important as it can provide means to minimize such deposits at the device surfaces. On the other hand, bone growth has long been known as responsive to electrical stimulation, and information on surface charge creation in bone or dental implants can foster healing and improve bone-implant bonding.

A number of metal oxide nanoparticles show high photocatalytic activity, which originates from the ability of these materials to generate surface charge that breaks water to form antimicrobial reactive oxidative species. These reactive oxidative species are very effective against Gram-positive bacteria such as the MRSA superbug. An understanding of the generation of surface charge and its associated photocatalytic property can lead to novel methods of exploiting photocatalytic nanoparticles more responsibly and more effectively in applications in which conventional methods have proven ineffective, *e.g.* in combatting hospital-acquired infections.

The origin of this book lies in many of its contributing authors' engagement in research and education in the field of manipulating surface charge in biomaterials through electrical, chemical and electro-chemical methods to mediate

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biological reactions to a desired end. A consortium, Bioelectric Surface, funded by the European Commission under the FP-7 NMP (Nanosciences, Nanotechnologies, Materials and new Production Technologies) programme, undertook a systematic study of electrical modifications of biomaterials to understand, control and exploit biological reactions. It was soon realized that information related to surface charge and its biological implications had been scattered over numerous specialist contributions in a range of scientific disciplines such as nanoscience and nano-biointeractions, nanomedicine, electrostatics, surface modifications, protein immobilization, polymer and ceramic processing, biomaterials, photocatalysis, clinical microbiology, biofilms, MRSA, textile processing, stent manufacture, restenosis, plaque resistance, encrustation, bone growth and so on. It was felt important that specialists from these varied disciplines require the learning the languages of each other to contribute effectively in this field.

This book is thus an attempt to bring more generalization into the concept of surface charge in biomaterials so that a researcher or a biomedical device engineer can find it useful to familiarize with the interplay of surface charge and its biological role that may influence the life and performance of a medical device. It provides non-specialist overviews of a number of concepts relevant to surface charge, its creation, control and measurements (Part I). The book then provides an overview of basic biological interactions such as protein and cellular interactions on solid surfaces (Parts II and III), before discussing some relevant biomedical applications in which manipulation of surface charge have been demonstrated or can be potentially exploited (Part IV).

The book benefits from the contributions not only from experts in different specialised fields such as nanomanipulation, protein immobilization or surface charge measurements, but also from practitioners such as clinicians and device engineers from industry. I would like to express my gratitude to all of them. The subject matter of this book is highly interdisciplinary and goes well beyond my own area of expertise. I would also like to thank Dr. Tewfik Soulimane, a structural biologist, who has played a critical role in planning the outline of this book.

I would like to thank Dr Merlin Fox, Commissioning Editor of the Royal Society for Chemistry, for inviting me to edit this book and for his patience and flexibility during the various stages of preparation and publication of this book. Finally, I would like to thank my wife, Sanjida, for her support and my daughters, Yasna and Iman, for being so lovely and accommodating during the preparation of this book.

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Part II Protein Interactions at the Surface

Part I
Electrostatic Charge on Biomaterials' Surfaces

CHAPTER 1

Electrical Modifications of Biomaterials' Surfaces: Beyond Hydrophobicity and Hydrophilicity

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1.1 Introduction

When a biomaterial is placed inside the body, a biological response is triggered almost instantaneously at the top few nanometres of the biomaterial. It is commonly understood that electrical properties such as local electrostatic charge distribution at biomaterials' surfaces play an important role in defining biological interactions *e.g.* protein adsorption and cell adhesion.[1,2,3] Protein adsorption is the initial event that takes place within the first few milliseconds at the biomaterial surface.[4] The adsorbed proteins interact with selected cell membrane protein receptors. The accessibility of cell adhesive domains (such as various specific amino acids of adsorbed vitronectin, fibronectin and laminin) may either enhance or inhibit subsequent cell attachments and proliferation.

Biological membranes such as those found in cell membranes are subjected to an electrical field gradient in excess of 10 mV m^{-1}.[5] In other words, a cell with a

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