Springer Series in Biomaterials Science and Engineering

Volume 8

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Aims and scope

The Springer Series in Biomaterials Science and Engineering addresses the manufacture, structure and properties, and applications of materials that are in contact with biological systems, temporarily or permanently. It deals with many aspects of modern biomaterials, from basic science to clinical applications, as well as host responses. It covers the whole spectrum of biomaterials – polymers, metals, glasses and ceramics, and composites/hybrids – and includes both biological materials (collagen, polysaccharides, biological apatites, etc.) and synthetic materials. The materials can be in different forms: single crystals, polycrystalline materials, particles, fibers/wires, coatings, non-porous materials, porous scaffolds, etc. New and developing areas of biomaterials, such as nano-biomaterials and diagnostic and therapeutic nanodevices, are also focuses in this series. Advanced analytical techniques that are applicable in R & D and theoretical methods and analyses for biomaterials are also important topics. Frontiers in nanomedicine, regenerative medicine and other rapidly advancing areas calling for great explorations are highly relevant.

The Springer Series in Biomaterials Science and Engineering aims to provide critical reviews of important subjects in the field, publish new discoveries and significant progresses that have been made in both biomaterials development and the advancement of principles, theories and designs, and report cutting-edge research and relevant technologies. The individual volumes in the series are thematic. The goal of each volume is to give readers a comprehensive overview of an area where new knowledge has been gained and insights made. Significant topics in the area are dealt with in good depth and future directions are predicted on the basis of current developments. As a collection, the series provides authoritative works to a wide audience in academia, the research community, and industry.

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Biomaterials for Implants and Scaffolds

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Preface

Contemporary biomaterials signify a class of synthetised materials to replace or support lost/damaged living tissues for restoring proper functionality. Over the past few decades, biomaterials have made enormous impacts on improvement of quality of life for millions of patients. Many leading causes of death, such as cardiovascular diseases, cancer, musculoskeletal trauma and injury, etc., have been alleviated by using substitutive biomaterials devices. Strong motivation to further advance healthcare and lower socioeconomic burden has continuously fuelled new breakthrough and innovation of biomaterials, making it one of the most exciting fields of research recently. The latest generation of biomaterials encompasses interdisciplinary sciences and cutting-edge technologies in materials, medicine, cellular and molecular biology, biochemistry, nanotechnology, multiscale modelling, advanced design and biomanufacturing, largely expanding materials knowledge and broadening biomedical applications.

Biomaterials have seen fast growth in two major areas on implantable prostheses and scaffold tissue engineering. Traditional implants aim to replace or support damaged and/or lost tissues, and as substituted, implanted devices stay with the living system temporarily or permanently. Rapid increase of implant recipients and life expectancy has been stimulating continuous inventions of new implant materials and novel treatment protocol. Modern implantable biomaterials, such as alloys, polymers and composites, possess enhanced mechanical, chemical and biological properties, enriched functionality and augmented biomedical performance, allowing them to be tailored in a particular application and for a specific patient. As a class of bio-products, implants have now evolved into a mature industry that employs more than 300,000 people and counts for over US$200 billion revenue globally.

By contrast, tissue engineering provides a relatively new therapeutical strategy to generate functional tissues or organs for the human body. As a fast emerging interdisciplinary area, tissue engineering offers great promise in solving the issue of significant shortage of organs or tissues facing healthcare nowadays. A landmark of tissue engineering has been the development of scaffolds, which use structured biomaterials to guide cells to generate neotissue under proper conditions. The current status of tissue engineering bears an overwhelming resemblance to that of implants in the 1970–1980s. The concept of repair or replacing with regenerated tissues/organs is being widely accepted in medical fields, and the demand has been becoming surprisingly high. It is for this reason that the biomedical industry is spawning a new revolution at present, where tissue engineering is rendering the next generation of implants that offers enormous potential to healthcare.

While being used for different therapeutical strategies, implants and tissue scaffolds share considerable commonality from a biomaterials perspective. First, biomaterials remain a central vehicle in both treatments by enabling materialised devices to interact with biological systems properly. Second, they both necessitate certain mechanical, chemical and physical properties of materials for support of and integration with surrounding tissues. Third, the boundary between them is becoming less distinguishable as witnessed by the developments of implants that are porous and degradable as well as scaffolds that are non-degradable for various treatment applications. In this book, we introduce the critical issues and challenges of biomaterials for both implants and tissue scaffolds.

This volume comprises 14 chapters with the balanced foci on both implantable and scaffolding biomaterials, each part consisting of 7 chapters. Just as the nature of biomaterials per se, the expertise of the authors in this book spans from a wide range of disciplines, including materials science, biochemistry, nanotechnology, biomedical engineering and clinical sciences. For understanding the sophistication of biomaterials development, the methodologies outlined in this volume range from computational modelling and design analysis (in silico), fabrication and laboratory tests (in vitro) to animal and human trials (in vivo). Each chapter offers a succinct but comprehensive discussion of fundamental concepts, research approaches and scientific data relevant to a particular area of applications, such as orthopaedics, prosthetic dentistry, interventional cardiology, vascular system and hard and soft tissue regeneration, while it is more a material-orientated, rather than application-orientated, volume.

For better understanding on the interaction of implants or scaffolds with hosting tissue, Chap. 1 introduces multiscale modelling of musculoskeletal tissues through micro-CT images, which provides an effective approach to analysing osseointegration of implants and bone ingrowth in scaffold. The comprehensions of structural details of tissues would potentially help optimise implant morphology and scaffold microstructures for creating a desired microenvironment. To surgically place an implant or scaffold to its host site in vivo, drilling or sectioning of bone or other tissues is often required. Chapter 2 introduces a computational procedure for modelling the insertion process of dental implant, allowing the assessment of the initial outcome of implantation by quantifying the biomechanical responses of bone, aiming to improve implantation surgery for short- and long-term outcomes.

Metals and alloys, as the most common constitutive materials for implants, have been long used and extensively studied. The latest progress seen in this area includes surface modification for promoting osseointegration. Chapter 3 proposes a novel mechanobiological framework for multiscale analysis and topographical design of implant in silico. Following this, Chap. 4 discusses different treatment techniques for desired surface properties and further describes cellular and molecular responses to surface topography and surface chemistry through the in vitro and in vivo studies.

Bioglass and ceramic materials have been widely used in prostheses, implants and scaffolds for their desired biocompatibility and mechanical properties. Chapter 5 provides a comprehensive overview in the advances in bioglass and glass ceramics from a materials perspective, which portrays the effects of different constituents, synthesis approaches as well as biochemical and biomechanical properties with an outline of broad clinical applications. Chapter 6 describes a specific application of glass ceramics in prosthetic dentistry, where in situ preparation and clinical resurfacing of glass ceramic prosthesis are studied through multiscale analyses in vitro and in silico, aiming to provide an in-depth understanding of their mechanical behaviours when delivering such materials to clinical use. Chapter 13, on the other hand, introduces bioglass to tissue engineering by developing novel bioactive scaffolds with multifunctional properties and desired nano-/microstructural features. It also explores the additive manufacturing approach for fabricating bioglass-based scaffolds. The in vitro and in vivo studies exemplify the capacity and advantages of such materials in tissue regeneration.

Polymer signifies another class of important biomaterials which have been extensively used in both implants and scaffolds. Polymer has been seen as a trend to replace metals and ceramics in many biomedical applications attributable to its versatility and flexibility in physical and chemical properties. Chapter 7 depicts two key applications of polymeric composites in arterial stents and tissue scaffolds. Arterial stents have been traditionally metal dominated, and the introduction of polymeric materials in this field has shown considerable potential for rendering the next generation of stents. Polymeric scaffolds featured in this chapter cover several important aspects of materials, microstructures, fabrication and in vitro and in vivo studies. Chapters 8 and 9 introduce the electrospinning technologies, further demonstrating the versatility of polymer materials in tissue engineering. Chapter 8 concentrates on biomechanical and biochemical properties of electrospun polymer scaffolds with a broad range of applications, such as bone. Chapter 9 focuses on tailoring materials properties specifically for soft tissue regeneration, such as wound healing. Chapter 10 explores differently structured polymeric scaffolds for periosteum tissue engineering, further demonstrating the flexibility for compositional and structural design. Chapter 14 also outlines the applications in cartilage tissue engineering. Following these in vitro and in vivo studies, Chap. 12 provides a series of computational design approaches for optimising scaffold structures made of polymers or other biomaterials, in which tissue ingrowth is modelled to predict the outcome in silico.

Hydrogel has seen extensive applications in tissue engineering in recent years for its compelling chemical and biological properties. Chapter 11 outlines the characterisation procedures of hydrogel scaffolds and provides some important biomechanical data through monotonic and fatigue tests. The damage assessment methods outlined in this chapter enable further understanding of scaffolding behaviours of the materials. Chapter 10 discusses the role of co-deposited hydrogel in polymeric scaffolds for periosteum tissue regeneration. Chapter 14 provides an overview in a range of naturally derived and synthesised injectable hydrogels for scaffold cartilage tissue engineering with substantial in vitro and in vivo data.

The book is expected to be of interest to the readers who are willing to become familiar with biomaterials knowledge and research methodologies for broad implant and/or scaffold applications. The style and language used in this book are intended to appeal to senior students, practising engineers and materials and biomedical scientists from a diverse background in materials synthesis and cellular and molecular studies to computational biomechanics. Substantial overviews are also provided for better appreciation to the background and progress in the field.

The book would not be possible without the tremendous contributions from all the authors, who are recognised experts and active researchers in the related fields. To them we sincerely apologise for the lengthy delay in seeing their manuscripts in print after rigorous reviews and final revisions. We would like to particularly thank Professor Min Wang, the series editor of Springer, of the University of Hong Kong for giving us this excellent opportunity and technical guidance to edit this volume. We would also like to extend our gratitude to the Springer Beijing Office, especially Ms June Tang and Mr Heather Feng, for their patience and professional work during the entire process of publication.

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