Preface

This book aims to give a general perspective on fabrication strategies for bioinspired materials and a collective review of their current and prospective applications.

Bioinspired materials can be defined as the organic or inorganic materials that mimic the nature. Biological materials acquire their functional diversity by hierarchical structuring. As our better and in-depth understanding of the processes through which this self-organization of complex forms increases, novel strategies for the synthesis of bioinspired materials will be adapted. Currently, a limited range of bioinspired materials are produced worldwide in the form of nanometals, composites, biopolymers, self-healing coatings, biosensors, and novel functional materials. These materials find usage in the areas related to engineering such as materials, biomedical, chemical, mechanical, civil, etc.

Novel and functional materials, structures and processes may be developed from adapting the abilities and mechanisms learned from nature. By using novel synthesis methods and art of the state characterisation techniques, the monitoring of the matter down to micro-/nano-scale helps in discovering new behaviors, such as quantum confinement and surface plasmon resonance (SPR). Novel fabrication methods based on bottom up approach including self-assembly and biomineralization, have been widely adopted to produce bioinspired materials having various functionalities such as self-healing, sensing and responsiveness, self-cleaning, etc.

This HoR will lead to increased knowledge on bioinspired materials and bioinspired processes, particularly through the replacement of conventional technologies. By means of specialized up to date reviews, a widespread characterisation of these novel materials will be made in nano-structural, physical, chemical, thermal and mechanical aspects and biocompatibility. Special consideration will be given to evaluate functional end-properties, e.g. self-healing. This will improve the current state of the art and understanding the knowledge gained through bioinspired materials engineering.

The broad range of exciting topics covered in this HoR will be of great interest to scholars, researchers and graduate students in materials science and engineering, nanotechnology, biotechnology and biomedical materials.

The HoR contains 12 chapters covering wide of topics devoted to bioinspired materials engineering. Hereafter a summary of the content related to chapter.

Chapter 1 presents one of the exciting topics “Green Synthesis of Metallic Nanoparticles using Plant Compounds and their Applications”. The advancement in nanoparticle system has an impact in scientific areas. Metal nanoparticles (MNPs) such as silver (Ag), gold (Au) and copper (Cu) were found to exhibit antibacterial and other biological activities. This biological activity is due to the extremely small size of the NPs (1–100 nm), which enhances their physical, chemical, magnetic, and optical properties. Many types of NPs have been introduced into biology and medicine. Areas of biosensors, tissue engineering,
DNA modification, drug delivery system are benefited by NPs. In recent years, several research have achieved success in the synthesis of Au, Ag, Cu, ZnO and Pd NPs obtained from the extracts of plants. The phytochemical constituents (Tannins, flavonoids, terpenoids, saponins, glycosides etc., present in the plant extracts were used for the green synthesis of NPs of desired size and morphology. Moreover, these active molecules act as reducing and capping agents for the synthesis of NPs, which makes these NPs suitable for biomedical applications. The synthesis of NPs, through physical and chemical methods, are well known; however, due to their environmental impact, energy consumption, and use of toxic chemicals, the synthesis of nanomaterials that uses a green approach is most preferable, as this type of approach is found to be ecofriendly and nontoxic. This ecofriendly approach might pave the path for researchers across the globe to explore the potential of different herbs in the synthesis of NPs. Nanoparticles have been reported to be green synthesized from various parts of plants such as the bark, leaves and various plant extracts. This chapter discusses the synthesis of various MNPs using plants and their phytochemical constituent’s involved in the synthesis. A section devoted to the different applications will be presented.

Chapter 2 presents the Toxic Effects of Engineered Nanoparticles on Living Cells. Because of their small-scale technology, NPs have the ability to interpose at a cellular level of living organs. NPs can easily enter into the living cells, which may cause hostile effects on the environment and human health. Meanwhile, the potential development of nanotechnologies is expected to become new source of human or environmental hazards through inhalation, ingestion, skin applications, or injection of engineered NPs in factories, drugs or the use of customer foodstuffs. Understanding the toxic effects of NPs on the environment and human health is the biggest obstacle to the safe development of nanotechnology. However, little is known about their toxic mechanisms. The main important question is whether the indefinite hazard of engineered NPs particularly their environmental impact are compensating their recognized benefits for human daily life. To fully understand and predict possible health effects following exposure to nanoparticles, information about their physicochemical properties and the NPs-living cell interactions are indispensable. In this chapter summarizes recent studies from the literature on the effect of engineered NPs on living cells which may ultimately establish exposure standards and recommended handling practices to avert significant human health risks in the future. Understanding these effects is essential to establish satisfactory regulatory policies on the safe use of NPs by human. The objectives of this chapter are to: (i) investigate the current state of engineered NPs in the environment; (ii) provide recent information about the main properties of some innovated NPs; and (iii) estimate whether this data are sufficient to facilitate their comprehensive and effective influence on living cells and human health.

Chapter 3 discusses Bioinspired Nanoparticles for Efficient Drug Delivery System. Bioinspired synthesis has emerged as a field of science that includes the study of how nature designs, processes and assembles/disassembles molecular building blocks to perform physiological events and then applies these designs in the synthesis of new molecules and materials with unique properties. Indeed, NPs that mimic the structure and composition of biological tissues, gain biocompatible characters and hence can be successfully implemented in biomedical applications. Living organisms have a unique property of self-delivery that is based on how layers in tissues are designed to have a selective permeability and how vesicles can carry specific molecules to a target through these tissues. The design and the process of such naturally occurring events have been an inspiration for many researchers in the application of drug delivery systems (DDS). This chapter presents the latest studies that focus in the process and mechanisms during bioinspired synthesis of NPs for the applications of drug delivery, mainly, for cancer drugs. Also,
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gene delivery, protein delivery and Calcium Apatite delivery are discussed. Synthesis of bioinspired NPs, characterization, uploading and release mechanism, biocompatibility and the toxicity are shown. The influence of these bioinspired designs on the efficiency of DDS is discussed.

Chapter 4 presents “Self-Assembled Biomimetic Scaffolds for Bone Tissue Engineering”. Cranial, maxillofacial, and oral fractures, as well as large bone defects, are currently being treated by auto- and allograft procedures. These techniques have limitations such as immune response, donor-site morbidity, and lack of availability. Therefore, the interest in tissue engineering applications as replacement for bone graft has been growing rapidly. Typical bone tissue engineering models require a cell-supporting scaffold in order to maintain a 3-dimensional substrate mimicking in-vivo extracellular matrix for cells to attach, proliferate and function during the formation of bone tissue. Combining the understanding of molecular and structural biology with materials engineering and design will enable new strategies for developing biological tissue constructs with clinical relevance. Self-assembly has become an effective and promising approach to synthesize a wide range of novel nano-sized biomimetic scaffolds, which could potentially be used in bone tissue engineering applications. It is a type of process in which a disordered system of pre-existing components forms an organized structure or pattern as a consequence of specific, local interactions among the components themselves, without external direction. In this approach, building blocks of the structure organize themselves into functional units driven by the energetics of the system. It thereby will be an attractive candidate for producing engineered bone grafts. Specifically, self-assembling peptides capable of in-situ gelation serve as attractive candidates for minimally invasive injectable therapies in bone tissue engineering applications.

Chapter 5 “Introduction to Bio-inspired Hydrogel and their Application: Hydrogels” presents an overview on the synthesis, characterization, and applications of covalently and physically cross-linked polymers. This class of molecule called hydrogels is defined by a covalently bonded polymer matrix that can hold at least twice its mass in solvent. Hydrogels are general classes of polymeric systems that have further subgroups: semi-interpenetrating networks (SIPN), interpenetrating networks (IPN), block co-polymers, grafted. The different methods to synthesize these hydrogels are discussed. Specific characterization techniques to evaluate the properties and functionalities of hydrogels are also described. Moreover, practical and industrial applications of hydrogels are detailed. Throughout this chapter, the different synthesis methods, characterization techniques, and current uses of hydrogels, are highlighted.

Chapter 6 reports on “Synthesis, characterizations and biological effects study of some quinoline family”. As organic based compounds, quinolone derivatives prepared by various chemical routes, show interesting antiseptic, antipyretic and antiperiodic properties (proposed as antimalarial, antitumor, antibacterial, antifungal, etc), thereby offer various potential applications in particular in biomedical field. In addition of being used in the synthesis of some compounds (fungicides, virucides, biocides, alkaloids, rubber chemicals and flavoring agents), they are used also as polymers, catalysts, corrosion inhibitors, preservatives, etc. Particular emphasis has been devoted to the their fascinating biological properties.

Chapter 7 presents a study on “Peroxovanadates and Its Bio-mimicking Relation with Vanadium Haloperoxidases”. The production of halogenated natural product compounds is prevalent in marine organisms. These compounds such as halogenated indoles, terpenes, acetogenins, phenols, etc., are important because of their unique biological activities or and pharmacological properties to volatile halogenated hydrocarbons which are produced on a very large scale. The function of the marine haloperoxidases is thought to be involved during the biosynthesis of these natural products. In the context of significant interest and concern about the synthesis of various halogenated natural products, the man-made peroxovanadium(V) complexes (i.e., peroxovanadates) are utmost alternatives to the naturally abundant
vanadium halopexidase enzymes which are very much well-known because of their high efficiency in producing such halogenated compounds. Moreover, these enzymes own fascinating potency of catalyzing selective oxidation of halides which is influenced by their protein active site and the role of certain amino acids in activation of vanadium(V)-bound peroxide for halide oxidation. It has been demonstrated that peroxovanadium(V) complexes, especially mono- and di- peroxovanadium complexes, possess structural similarity with the active site of vanadium haloperoxidase enzymes. Interestingly, peroxovanadium complexes are a classes of compounds which also fairly active in other biological processes as well as catalytic oxidations. With this viewpoint, a large number of peroxovanadium complexes have been synthesized and studied for their reactivity in relation to the vanadium haloperoxidases. However, only few of peroxovanadium complexes are found to mimic both structurally and chemically with the vanadium haloperoxidases. In this context, this chapter provides an overview of functional bio-mimicking nature of peroxovanadium complexes with haloperoxidase enzymes. In addition, noteworthy attention has been dedicated to examine the reactivity of vanadium haloperoxidases with mechanistic approach.

Chapter 8 deals with “A Bio-inspired Phenomena in Cementitious Materials: Self-healing”. Today’s modern cementitious composites has undergone a great change in terms of ingredients used and mix design since the discovery of Portland cement two centuries ago. These changes are affiliated with the production techniques of Portland cement becoming more efficient, energy effective and eco-friendly day by day. Inclusion of natural pozzolans and industrial by-products as cement replacement materials and chemical admixtures facilitate production and enhance the properties of these composites in terms of strength and durability. Not only the ingredients and their amounts in the cementitious systems but also the expectations from these materials and systems evolved. As it is easier to ensure strength requirements by improved constituents, design and quality control techniques; enhancement of these materials’ service life has become an issue. Considering the substantial amounts of cementitious composites, especially concrete, produced worldwide, decreasing the cost of maintenance and repair of these structures have become major challenges. Although research on self-healing composites spreads with autonomic healing of composites via encapsulation in the beginning of this century, concrete technologists knew that cement paste can heal itself autogenously from Glanvilles’ studies date back to 1930s. Thus, it is not a surprise that this bio-inspired phenomenon has gained interest in the cementitious composites research area, most of the techniques such as vascular systems and microcapsules containing polymer or mineral-based self-healing agents as well as biological intervention methods has proved their effectiveness in the laboratories and pilot studies. While the research in this area is emerging, extending in-site utilization of these techniques via mass production is a necessity. This chapter focuses on the history and importance of self-healing cementitious composites and its respective terminology, explains the types of self-healing mechanisms as well as the factors affecting these mechanisms and guides the reader to select the appropriate self-healing technique for a specific case. Finally, test methodology to verify the effectiveness of self-healing is discussed in view of specific examples from the literature.

Chapter 9 “Impact of Electrospun Biomimetic Extracellular Environment on Proliferation and InterCellular Communication of Muscle Precursor Cells; An Overview: InterCellular Communication of Muscle Precursor Cells with Extracellular Environment” mainly focuses on the synthesis and characterization of electrospun nanofibrous matrices as a novel biomimetic scaffold for the cultivation of muscle cells. In recent years, many research groups have presented various techniques of engineering 3D skeletal muscle tissue. However, the possible approach for in-vitro cultivation of muscle cells seems to be tissue engineering. Tissue engineering is an interdisciplinary branch of science which integrates the benefits of life sciences and medicine with those of engineering. In order to cultivate muscle cells under in-vitro
conditions, it is necessary to have a 3D scaffold. Additionally, in tissue engineering applications, the biological cross talk between cells and scaffold is controlled by the material properties and scaffold characteristics. In this chapter, the fabrication of novel nanofibrous scaffolds via electrospinning technique for the cultivation and propagation of skeletal muscle precursor cells, is presented. Moreover, this chapter provides a general overview of the common approaches and techniques used for designating nanofibrous scaffolds for culture of cells specifically muscle cells. The limitations and benefits of the tissue engineering are discussed.

Chapter 10 deals with “Engineered Gellan Polysaccharides in the Design of Controlled Drug Delivery Systems”. Gellan gum is one of the widely studied polysaccharides in the field of drug delivery science and technology. This natural polymer is nontoxic, biodegradable, and easily amenable to different chemical modifications owing to the presence of a number of hydroxyl and carboxyl groups in its chemical structure. Recent studies have demonstrated that the polymer can be chemically modified to meet the desired drug delivery needs such as pH-sensitivity, modulation of gel and self-assembled characteristics, prolongation of drug release, temperature-dependent sol-gel properties. Hence, this chapter will provide different modification procedures along with the intended drug delivery applications of modified polymers.

Chapter 11 is devoted to “Bioinspired Materials and Biocompatibility”. Mimicking the nature is the state of the art in the materials science in this century. As the material features are changing very rapidly, the biocompatibility definition is evolving to fulfill the alteration in this field. Especially in tissue engineering, biomimetic structures are gaining great importance to mimic extracellular matrix to have a functionalized surface to facilitate tissue regeneration. Performing a risk assessment for any medical device or biomaterial needs a biological evaluation in respect of its possible non-or low toxic effects. And the ISO 10993 series provide some in-vitro and in-vivo assays that can be used either separately or combination of both. Considering the ethical issues for animal welfare, in-vitro and in-vivo assays may be used together to get adequate information that helps making a decision on the possible toxicity of a medical device or biomaterial, which is essential for the safety evaluation and risk assessment. To determine the biocompatibility of the bioinspired materials the tests should be carried out under the regulations of ISO 10993 and new test systems should be developed and validated. In this chapter, the general biocompatibility concept, test systems to determine biocompatibility, examples of bioinspired materials and their altered biocompatibility and future expectations from these novel bioinspired materials will be discussed.

Chapter 12 is dedicated to “Synthetic Approaches to Biology.Engineering Gene Control Circuits, Synthesizing and Editing Genomes”. Nanobiotechnology and synthetic biology are emerging as novel fields that integrate research from science and technology to create novel organisms with new desired properties. We present here the new revolutionary methods of synthetic biology that enable us to engineer gene control circuits, edit genomes, and create de novo whole genomes. The creation of new genomes that function in the cell means that we can create new organisms that are different from those observed in nature. The synthetic genomes can contain novel combinations of genes that offer the opportunities to create novel biological species that possess predefined combination of properties. Therefore, the synthetic genomes can be regarded as a new kind of materials. The methods for whole genome assembly applied so far combined several in-vitro and in-vivo steps that possess certain technical limitations and shortcomings. In this chapter, all technical aspects of assembling novel genomes and their current limitations, will be discussed. The genome editing technologies that have been developed over the last several years based on the CRISPR-Cas system is also discussed. In addition, major RNA-based methods for design of gene control circuits both in prokaryotes and eukaryotes, including humans, will be presented.
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This book will bring new insights and most recent up-to-date advances research work related to bioinspired materials and engineering, with the emphasis on some selected hot topics such as green nanotechnology, functionalisation and application of metal oxides nanomaterials, interaction of nanomaterials with living cells, self-healing based on cementitious materials, gene control, biocompatibility, control of drug delivery systems by using polymers, biomimetic scaffold for the cultivation of muscle cells, hydrogel and peroxovanadates, quinoline derivatives, and self-assembled biomimetic scaffolds for bone tissue engineering. Both experimental and fundamental results were presented, figures and tables illustrations are used whenever needed, in order to facilitate better understating such fascinating multi-disciplinary field of research to the wide range of readers with different background and level.