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Editorial overview

Biomimetics

Rui L. Reis [a,b,*]

[a] Director of the 3B's Research Group Biomaterials, Biodegradables and Biomimetics, Campus de Gualtar, 4710-057 Braga, Portugal
[b] Department of Polymer Engineering, University of Minho, Campus de Azurém, 4800-058 Guimarães, Portugal

Mineralised tissues such as bones, tooth and shells have attracted, in the last few years, considerable interest as natural anisotropic composite structures with adequate mechanical properties. In fact, Nature is and will continue to be the best materials scientist ever. Who better than Nature can design complex structures and control the intricate phenomena (processing routes) that lead to the final shape and structure (from the macro to the nano level) of living creatures? Who can combine biological and physico-chemical mechanisms in such a way as to arrive at ideal structure-properties relationships? Who, other than Nature, can really design smart structural components that respond in situ to exterior stimulus, being able of adapting constantly their microstructure and correspondent properties? In the philosophy described, mineralised tissues and biomineralization processes are ideal examples to learn from for the materials scientist of the future.

Typically, the main characteristics of the route by which the mineralised hard tissues are formed is that the organic matrix is laid down first and the inorganic reinforcing phase grows within this organic matrix/template. Nevertheless, to date neither the sophistication of the biomineral assembly mechanisms nor the rather complex composite microarchitectures could be duplicated by non-biological methods. This is true in spite of the fact that substantial progress has been made in the understanding how biomineralization occurs. However, most of this knowledge is yet to be used on relevant industrial applications, namely in the design of appropriate biomimetic routes.

Biomimetics is a new, very important, field of science that studies how Nature designs, processes and assembles/disassembles molecular building blocks to fabricate high performance mineral-polymer composites (e.g., mollusc shells, bone, tooth) and/or soft materials (e.g., skin, cartilage, tendons) and then applies these designs and processes to engineer new molecules and materials with unique properties. When we decided how to organize this special section on biomimetics the main aim was to provide the reader with a collection of papers that would review the actual scientific knowledge and recent R&D developments on biomineralization phenomena, especially those related to organic polymeric matrixes. The section should help readers to understand the fundamentals involved, and to comprehend the present state of the art in the use of bioactive ceramics and glasses and other mineralized materials for bone regeneration and replacement, trying to discuss what can be learned from Nature in order to develop new biomaterials. And finally it should help us to see how one can use the understanding of biomineralization processes to develop new biomimetic materials and processing routes that can lead to industrial applications.

The first paper by C. Li and D. Kaplan addresses the topic of biomimetic composites produced via molecular scale self-assembly and biomineralization. It discusses possible biomimetic strategies based on molecular scale mimicry. It goes from the topic of bone-like materials mimics, to silica based complex skeletal structures that can be found in many marine organisms. The role of fibrous proteins in biomineralization is then discussed, as it is the possible template effects of the organic macromolecules. In this case the synthesis of calcium carbonate films is used as an example. The review argues convincingly that new molecular insights into components and their interactions related to biomineralization are aiding a lot in advancing our understanding of the synthesis of complex systems that can be found in Nature.

The review by S. Davis, E. Dujardin and S. Mann is focused on very recent advances in bioinorganic materials chemistry, especially on those reported during the past eighteen months. The review demonstrates that these advances are providing much impetus for current developments in nanostructured materials. It tries to demonstrate how specific molecular recognition and self-assembly processes can inspire the development of

* Tel.: +351-253-604781/2; fax: +351-253-604492.
E-mail address: rgreis@dep.uminho.pt (R.L. Reis).

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complex materials at all length scales. The review discusses in detail the recent findings on ordered structures based on amorphous biominerals. Then it moves to the topic of biomolecule/nano-particle conjugates, addressing for instance the control of DNA-based nanoparticle assemblies and the possible applications that one might expect from further advances in this line of research. The formation of nanoparticles in-situ, within performed biological or biomimetic templates, is then discussed and several examples are given. In summary this paper illustrates well some of the key biomolecular-based approaches being developed with the aim of producing inorganic materials with a complex form.

B. Ben-Nissan addresses the topic of natural bioceramics. The paper starts by reviewing briefly the field of bioceramics, comparing synthetic and natural origin ceramics with potential applications in medicine. The review then moves to the topic of bone and bone grafts, discussing the possible use of autografts, allografts, dimineralised bone matrix (DBM), or synthetic graft materials. Then the review present the potential of coralline based apatites for being used as bone graft materials and concludes with some insights into the use of bioceramics combined with cells and/or growth factors in the fields of bone regeneration and tissue engineering.

The paper by H.-M. Kim discusses the principles of ceramic bioactivity and possible lessons that one can obtain by means of understanding bioactivity. This can then be used to design novel biomimetic strategies to coat implant materials with calcium-phosphate layers. The paper addresses the in-vitro and in-vivo fundamentals of ceramic bioactivity, including the mechanisms of tissue-integration and surface chemical factors involved in calcium-phosphate deposition. Finally it discusses biomimetic approaches, going from topics such as surface functionalization to induce bioactivity, up to the design and processing of ceramic-polymer nano-hybrids, biomimetic calcium-phosphate/polymer composites and the use of bioactive matrices and scaffolds on hard tissue engineering.

The 5th paper by J. Jones and L. Hench discusses the use of porous ceramics on the regeneration of trabecular bone. The review is mainly focused on the development of 3D scaffolds that can be used on bone tissue engineering. The paper discusses mainly the use of 3D architectures obtained from sol-gel bioactive glasses. Initially the need for bone biomimetics is briefly addressed. Then the review moves from the concept of replacement to the one of regeneration. That leads to defining the ideal scaffolds and their properties. Bioactive materials and their potential for this type of application are then reviewed. Several ways of processing scaffolds made from porous bioceramics are described, ranging from the possible porogens that might be used, to the polymer replication technique, direct foaming techniques and gel-casting methodologies. Finally the foaming of bioactive glasses and particularly of sol-gel bioactive glasses is addressed. The review finishes with the potential for using rapid prototyping for designing custom made implants and gives the authors' opinions on some future directions.

The last paper in this section comes from my own group, being authored A.L. Oliveira, J.F. Mano and R.L. Reis. It addresses the development of Nature-inspired calcium phosphate coatings, discussing the present status of the field and some novel recent advances and mimicry approaches. It combines the topics of biomimetics with the attempts to use these concepts for designing better materials for bone replacement and bone tissue engineering scaffolding. The paper starts by discussing mineralized tissues and some lessons one might obtain from understanding the types of structures found in Nature. Then it moves to discuss the properties of bone as a material in order to introduce the reader to the concepts involved on calcium-phosphate bone-like coatings, discussing in detail the present research status in this field. Finally the review integrates all previous concepts to discuss the application of biomimetic approaches to produce Ca–P coatings focusing specially on the difficulties involved on coating biodegradable polymers and degradable tissue engineering scaffolds.

The collection of six papers provides the reader with very useful information on new developments in the field of biomolecular materials chemistry, molecular self-assembly and biomineralization, biomimetics, and on its possible applications—especially on some bone related applications. The review papers clearly demonstrate the evolution and growing of the field of biomimetics and disclose some new trends that might be expected in the future to further develop the art and science of mimicry.