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Inspired by Nature
Materials biomimicry to support human activities

By

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Abstract

The classes of materials used in the biomedical field are manifold: metals, ceramics, polymers and their composites. All these materials are often used in synergic combination in order to meet different requirements. In the design of a biomedical device and in the selection of the materials it is made of, the requirements are particularly stringent since, in addition to carry out its primary function, the device itself must not hamper the host body.

Therefore, biomaterials must, first and foremost, ensure biocompatibility.

Aiming at the synergic integration of implanted biomaterials with the host organism, a design framework results crucial: biomimicry. It is straightforward to get inspiration from structures and solutions occurring in Nature in order to design devices intended to operate in symbiosis with a living organism.

The work presented in this thesis was conceived and developed within such outlook. Two major topics were addressed: ElectroActive Polymers (EAPs), used as artificial muscles and Magnesium foams, used as orthopaedic implants.

As far as EAPs are concerned, it was studied their implementation in actuation devices manufactured according to bioinspired geometries, which can reproduce as faithfully as possible the structure of natural muscle tissues. In fact, in line with the principles of biomimicry, the structures proposed recall the human physiology of muscle bundles, and allow the integration of a recruitment mechanism of the motor units.

EAPs have a typical transducers behaviour: if prompted with an electric signal (in particular a voltage), they react with a mechanical deformation, and vice versa. Therefore, EAPs can be described as smart materials, suitable to be used both as actuators and as sensors. As actuators, EAPs have several advantages over the solutions currently present in the state of the art of traditional robotics. In fact,

EAPs allow more fluid and biomimetic movements, if compared to those achievable with mechanical counterparts: polymers are flexible and not limited by the rigidity of devices relying on gears and bearings. For this reason, and thanks to stress and deformation values similar to those of biological tissues, EAPs are also referred to as "artificial muscles" [1].

As far as magnesium foams are concerned, within a biomimicry outlook, the context of orthopedic surgery sets the morphology of natural bone as reference. Designing choices regarding materials selection, production methods and treatments (in bulk and/or on surface) were addressed to reproduce the mechanical and functional features of natural bone. In fact, if on one side the orthopaedic implant is required not to collapse under the mechanical load applied, on the other it should not bear excessively or exclusively the forces acting on the bone in order not to induce a stress-shielding effect. This phenomenon, in fact, may be critical since it reduces considerably the stimulation of regenerative bone cells and, ultimately, slows down the recovery of natural bone. The natural bone has a complex structure, resulting from millions of years of evolution, which fulfils several functions: it provides specific structural support, locally adapted to load conditions; it does not add unnecessary weight by means of an optimized minimization of mass and it allows nutrients supply to tissues through adequate vascularization. Such multi-functionality is enabled by the peculiar structure of the spongy bone tissue. Starting from these observations, the mimesis of cancellous bone conformation is one of the most appropriate guideline in choosing and designing materials for orthopaedic applications.

Among the feasible technological solutions, metallic foams with open interconnected porosity have been identified as the most promising choice [2]-[5] and this thesis is focused on this solution. In fact, these materials can be designed to combine the mechanical properties and the morphological characteristics of natural bone, as well as the vascularization function and the stimulation of bone tissue growth. Furthermore, metallic foams represent one of the most suitable option to coherently develop a biomimetic device that reproduces the main features of natural bone.

In the light of the requirements outlined so far, pure magnesium represents an optimal solution. This metallic material in fact meets the multi-functionality requirement previously described: it has mechanical properties of the same order of magnitude as those of natural bone tissue, it can be produced in the form of foam, it is biocompatible and bioresorbable. This last feature enables the possibility to avoid second surgery usually needed to remove orthopedic devices once their function is fulfilled. Supporting this choice, there is a wide scientific literature which, in recent years, has recognized magnesium as a very promising material for biomedical applications, although there are still some critical aspects to be solved. In fact, the process of corrosion of magnesium in the body fluids results in the formation of gaseous hydrogen that, if produced too rapidly, can be harmful for the human body [4].

References

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