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Editorial

Applications of Hydroxyapatite Nanocoatings and Nanocomposite Coatings in Dentistry

Andy H. Choi* and Besim Ben-Nissan

Faculty of Science, School of Mathematical and Physical Sciences, Australia
Faculty of Science, University of Technology Sydney, Australia

***Corresponding author**

Andy H. Choi, School of Mathematical and Physical Sciences, Faculty of Science, 745 Harris Street, Ultimo, NSW 2007, Australia, Tel: 61-02-9514-8205; Email: andy.choi@uts.edu.au

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EDITORIAL

The obvious choice in the deliberation of an ideal biomaterial to mimic and replace bone is synthetic calcium phosphate due to the fact that they possess the same structure and composition as the biogenic apatite which is a bone mineral. However, despite having a composition similar to that of human bone, the mechanical properties of calcium phosphate are far from being close to those of human bone as a result of their inorganic nature and brittleness. Consequently, this restricts their utilization in load-bearing applications without further modifications [1-5].

Hydroxyapatite (HAp) is commonly acknowledged as a bioactive, biocompatible, and osteo conductive material chemically resembling the mineral component of teeth and bone [6,7]. HAp belongs to the calcium orthophosphates family, being the less soluble compound in its class in physiological aqueous environments, second only to fluoroapatite. In a study by LeGeros and Ben-Nissan [8], bone-like apatite can be better described as carbonate HAp and approximated by the chemical formula: $(Ca,Mg,Na)_{10}$ $(PO_4,CO_3)_6$ $(OH)_2$. Their structure and chemistry, which plays an influential role in their rates of solubility and dissolution within the human body, is used to classify the various types of calcium phosphates [1-5,9]. As the calcium phosphate comes into contact with bodily fluid, its surface ions can be exchanged within the physiological environment. Different ions and molecules such as proteins and collagen, on the other hand, can be adsorbed onto the surface [1].

One of the important benefits of using HAp as a bioactive coating is that it could act as a reservoir of calcium and phosphate ions, which in turn may stimulate the growth of bone tissue on and toward the implant, ensuring its strong interfacial bond with the living tissues. It was stated in a study by Hench [7] that the ideal environment for bone growth is achieved when good mechanical inter-locking is established, the availability of a bioactive surface, and metal ion release is reduced. In animal models, some implants coated with a thick-layer of HAp have shown extensive bone apposition [1-5].

Nanotechnology has created unique approaches in the production of bone-like synthetic nanopowders and nanocoatings of HAp. Nanoparticles of HAp have generated new opportunities in the design of superior biocompatible coating for implants and the development of high-strength dental nanocomposites. Nanoplatelets and nanoparticles of HAP provide excellent bioactivity, resulting from the very high surface area for integration into bone. At present, a number of coating techniques have been used for the fabrications of HAp micro- and nanocoatings. However, each suffers from disadvantages that prevent it from being the ideal coatings technology (Table 1).

Nanocoatings are thin films composed of an isotropic and homogeneous compound with thicknesses below the range of micron-sized coatings, i.e. less than 1 µm. Multiple layers can be synthesized easily with excellent biological, physical, and chemical properties. For a single coating, the usual thickness is below 100 nanometer. Advantages of nanocoatings include the ease of application and synthesis methods, purity as a result of the selection of raw materials, and the capacity to be mixed with other nanoparticles or compounds to produce nanocomposite coatings and bulk nanocomposite materials, if required [1-5].

Quality HAp-coated implants encourage rapid healing and attach more completely to the bone [3]. Coating properties such as constituent phases, crystallinity, porosity, implant surface roughness, and thickness will influence the long-term performance of a HAp-coated implant. Along with the effects of chemistry and surface topography, it was discovered that relatively thin depositions of plasma spray-coated HAp onto implants increased the bond strength between bone and implant as well as to accelerate early bone formation. On the other hand, a good balance must be achieved between the solubility of the coating and the rate of bone growth. This would allow sufficient mechanical bonding strength at the implant-tissue interface, and thus would enable the long-term functionality and survival of the implant [2].

Nanocomposite Coatings

Nanocomposites coatings and nanocomposites in general can be defined as a mixture of two or more materials that

Table 1: Advantages and drawbacks of different coating techniques and the coating thickness produced (Modified from [10]).

Deposition Technique	Coating Thickness	Advantages	Drawbacks
Aerosol Deposition	1 - 5 µm	1. Room temperature technique. 2. Dense and well-adhered thick and thin coatings. 3. Same composition between starting material and resultant coating.	1. Line of sight technique. 2. Further exploration needed as not commonly used (both research and commercial scale).
Electrochemical Deposition	0.05-0.5 mm	1. Low cost. 2. Coat complex shapes. 3. Rapid. 4. Uniform coating thickness.	1. The bonding strength between coating and substrate is not strong enough.
Electrophoretic Deposition	0.1-2 mm	1. Coat complex shapes. 2. Rapid. 3. Uniform coating thickness.	1. Difficult to produce a crack free coating.
Plasma Spraying	30-200 µm	1. Low cost. 2. High deposition rate.	1. High temperature induces thermal decomposition. 2. Line of sight technique. 3. Amorphous coating due to rapid cooling.
Pulse Laser Deposition	0.05-5 µm	1. Coating by crystalline and amorphous phases. 2. Both porous and dense coating.	1. Line of sight technique. 2. Low deposition rate. 3. Expensive.
Sol-Gel	50-400 nm	1. High purity. 2. Homogeneous. 3. No residual stresses. 4. Complex shapes can be easily coated.	1. Edge cracking might occur. 2. Cannot induce mechanical interlock. 3. Post-treatment needed (curing).
Sputter	0.5-3 µm	1. Dense and uniform coating thickness on flat surface.	1. Amorphous coating. 2. Line of sight technique. 3. Time consuming. 4. Low deposition rate. 5. Expensive.

Table 2: Benefits and Issues concerning the nanomaterials used in the fabrication of HAp nanocomposite coatings (Modified from [4]).

Material	Benefits	Issues
Bioactive Glass	1. Improves the bioactivity of metallic implants. 2. Increased surface bioactivity.	1. Special attention is required in controlling the surface reactivity rates.
Carbon Nanotube (CNT)	1. Can be used to reinforce HAp. 2. Excellent mechanical properties.	1. After degradation of the matrix (HAp), possible transfer to internal organs. 2. Contains some free graphite, are difficult to disperse in the matrix homogeneously, and agglomeration occurs.
Collagen	1. Formation of new bone tissue without encapsulation. 2. Improved osteogenic effects even for a coating thickness of below 100 nm.	1. Further exploration needed on nanocomposite coating fabrication techniques.
Silica	1. Used to alter the surface and interfacial properties of HAp composites.	1. Long-term *in vivo* reliability. 2. Long-term adhesion to the implant.
Titanium Dioxide (TiO_2)	1. Capable of inducing cell growth and enhancing osteoblast adhesion.	1. Careful phase type and crystallinity control is needed.

include nanoscale particles and a matrix material. However for applications in the dental and biomedical arena, the matrix must be a biocompatible ceramic, metallic, or polymeric material. It is possible with the composite approach and the inclusion of secondary nanoparticles to control the mechanical properties of the composites such as the elastic modulus closer to those of natural bone [1-5].

The mechanical properties of the nanocoating can be further increased through the formation of HAp nanocomposite coatings by combining it with other micro- and nanoscale-based materials such as carbon nanotubes as a secondary phase. This approach is currently being investigated in the development of a new generation of nanocomposite coatings containing nanomaterials such as bioglass and collagen to promote osseointegration (Table 2).

Final Remarks

At present, a major drawback of synthetic implants is their failure to adapt to the local tissue environment. Cells do not adhere adequately or directly to most metallic surfaces despite the fact that implant materials such as titanium and its ternary alloys such as Ti-6Al-4V have been successfully used in dental implants and prostheses for more than 25 years. Intimate tissue in-growth is the ideal mechanism for fixation and the purpose of using nanocoatings and nanocomposite coatings is to modify the surface properties of dental implants to speed up the healing process. As previously mentioned, HAp-coated implants have been shown to display extensive bone apposition in animal models.

In spite of the effects of nanotechnology are generally believed to be extremely beneficial, consideration has to be given to the potential risks associated with nanomaterials. At the moment, there is a lack of standards governing as well as regulating the application of nanomaterials for dental applications and no effective approach in determining and assess long-term exposure risks to patients.

All calcium phosphate do not pose a long-term problem as they are both non-toxic and biocompatible; on the other hand, all other non-biogenic nanomaterials should be considered thoughtfully for their appropriateness in dental and biomedical applications. Issues may also arise from partial nanomaterial toxicity and safety profiles, which subsequently may influence a wide range of long-term medical problems.

The relationship between surface properties of nanomaterials and biological responses is one of the key issues in biomedical materials research at the moment. Surface modifications have become an essential tool in the understanding of how the chemical properties and structural surfaces effect the material-tissue interactions. It is anticipated that controlling tissue response using surface modifications will create opportunities in the development of new and superior dental and maxillofacial implants and devices at a quicker pace and in a more systematic manner than at present.

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