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Biocompatibility and Osseointegration of Nanohydroxyapatite

Review Article

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Abstract

Hydroxyapatite is the most important mineral component of bones and teeth. Hydroxyapatite is also called hydroxyapatite (HA). HA is used to reconstruct the damaged hard tissue for several reasons which include traumatic or non-traumatic events, and congenital diseases. The hydroxyapatite crystals present in the human body are there in both bone and teeth. In the human bone, the HA crystals act as a bioactive ceramic cover of about 65 - 70% by the weight of bone. This hydroxyapatite is an inorganic component. The HA crystals are arranged in different sizes and shapes which provides support for the tissue with structural durability, stability, function, and hardness. About the concern of dental role in hydroxyapatite crystals, it covers the dentin and enamel by 70-80% by weight. The hardest substance with relatively large hydroxyapatite crystals present in the human body is in the enamel. A is the main material of light which reflects by covering the pores on the enamel surface which will make the enamel appear semi-translucent. Recently the HA crystal is most widely used in dental implants because of its excellent osteoconductive property which supports the osseointegration and osteogenesis process. This article gives a short review of the biocompatibility and osseointegration of hydroxyapatite.

Keywords: Dental Implant Coating; Bioactivity; Bone Tissue Engineering; Osteoconductivity.

Introduction

Hydroxyapatite is a material that has multiple uses because of its biocompatibility and osseointegration with a resemblance to the nonorganic bone structure. Hydroxyapatite is the basic primary material that is used in dentistry and orthopedics. This hydroxyapatite is used in many dental specialties such as Implantology, Oral and Maxillofacial Surgery, Periodontology, and Esthetics. Recently, this hydroxyapatite is most commonly used as an Implant material because of its excellent osteoconductive property which gives the best support for the osseointegration and osteogenesis process. This is used to increase the thickness of atrophic alveolar Ridges, used in cystectomy to fill the bone defects [1].

In teeth, the enamel is the most mineralized tissue of the human body. In, the same way Hydroxyapatite is the main component of enamel, which has a bright white appearance and eliminates the reflection of light by closing the minute pores in the enamel surface. Hydroxyapatite is an important source of calcium and phosphate, and remineralization occurs in the demineralized enamel areas [2]. HA in a granular form is currently used in clinical dental practice for the reconstruction of periodontal bone defects [3].

Hydroxyapatite can be used in bone tissue engineering, dental implant coating, orthopedic applications, restoration of the periodontal defect, remineralizing agent in toothpaste, drug delivery, and gene delivery, and desensitizing agent in post teeth bleaching. [4].

Issues of Concern

Hydroxyapatite has been long term used in hard tissue engineer-

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ing because of its high chemical similarity to the mineral hard tissue. In the 1950's the bioceramics were used to fill the bone defects, but now recently the hydroxyapatite crystals are used to fill the bone defects. The interlocked porous structure has been provided in the hydroxyapatite based Implants. This interlocked porous structure acts as the extracellular matrix which promotes the natural process in cellular development and for tissue regeneration [5, 6].

Moreover, the HA increases the osseointegration and biocompatibility process by promoting through the rigid anchorage in between the implants and surrounding tissues in the bone without forming the growth of fibrous tissue. The bone anchorage should retain for a longer period in the successful osseointegration which will hence provide a complete functional ability [7, 8].

Furthermore significant applications of HA have been seen in dentistry since 1979. The HA cylinders have been used for the replacement of teeth. In the Era of 1980's this restorative dental procedure was used to enhance the bone fixation which was followed by utilizing the HA blocks. But recently, the HA is not only found in the dental cement and fillings but also in the tooth paste. The HA in toothpaste is used to decrease the deposition of layers on teeth and it acts as a polisher [9, 10].

The HA application can also be found in drug delivery. In physiological conditions the nano- HA contributes to a longer degradation rate. For the surgical placement or injection this local drug delivery can be useful as a carrier. Hence, the controlled drug delivery using HA will maintain the drug concentration in blood and it will reduce the toxicity to the other organs [11, 12].

The HA has several methods to produce either from synthetic material or through natural sources. Synthetic Hydroxyapatite uses raw materials in the form of calcium carbonate, calcium hydroxide, calcium nitrate, ammonium hydroxide, and diammonium hydrogen phosphate. The HA fabrication process is called as wet method and solid-state reaction , which is followed by calcination or sintering process. Both the wet method and solid state method are used by chemical reaction by varying the content of calcium oxide and tricalcium phosphate to reach the hydroxyapatite in the stoichiometric conditions [13].

The wet method process produces a non-stoichiometric Hydroxyapatite powder, with more impurities such as ions of hydrogen phosphate, carbonate, sodium and chloride. These HA impurities cause the formation of calcium deficient. On the other hand, this solid state reaction produces a stoichiometric and well defined crystals shape of HA product. But even though this solid state reaction requires high temperature and long heat treatment procedures. If the crystalline size increases then it will cause a decrease in porosity, which is associated with the aging process [14, 15].

Clinical Significance

For the hard tissue repair over the Autograft and Allograft the synthetic and natural hydroxyapatite have long been preferred. Usually these grafts will have problems with several natural issues such as shortage of grafts, morbidity of donor site, graft rejections and disease transmission [16].

The bioactivity of HA in bone tissue engineering, has proved to support the osseointegration through the osteoconductive and osteoinductive process. The property of Osteoconductive in HA provides a way to guide the new bone formation on the surface of the pores to the implant body. To the formation of strong tissue - implant interface the hydroxyapatite osteoconductive property allows the osteoblasts to attach, grow, proliferate and then phenotypes get expressed in a direct contact manner. The specific geometry and pore size of HA depends upon the osteoconductive property. The osteoconductive property of HA has the purpose for tissue ingrowth in which the neoformation of bone occurs in the non-bone forming areas. By coating the implant using HA increases the initial mechanical stability post implantation which results in the decrease of aseptic loosening. HA combines with the chemical bonding of the implant with the surrounding tissue which absorbs the protein into the implant surface. To the early healing event at the tissue implant surface the presence of protein on the surface will be favorable. The implant gives high stability which makes the immediate loading more predictable. The chemical presence of HA to the bone minerals will ensure its ability to bond directly to the bone tissue with any intervening fibrous layer. Application of HA as the cellular matrix plays a major role [17-19].

The advanced material fabrication process which leads to the development of Nano - HA particles and induce the fast dentin remineralization. The demineralized collagen matrix of dentin gets diffused in the Nano-HA which act as a mineral precursors by the changing the environment into a suitable scaffold for the remineralization process. Nano - HA provides a good source of calcium phosphate. This calcium phosphate is an important element to promote the protection against dental caries and erosion. The presence of Nano-HA in toothpaste acts as a filler particle to repair the holes and to surface the enamel at lower levels. During this reparation process, to replace the phosphate and calcium ions which have dissolved, the Nano- HA gets through the surface of the enamel. Thereby remineralizing the damaged enamel and to reconstruct its structural integrity. However, the Nano-HA in toothpaste will also provide a protective coating over the dentinal tubules. This offers a fast and potential relief from the tooth hypersensitivity [20, 21].

The Hydroxyapatite is quite strong in atomic bonds which contributes to the fact that the HA does not swell or change in size under the range of temperature and PH [18]. The most common problem because of the low swelling ratio of HA is drug delivery, the HA forbids the outburst of drugs. Bone cement in the HA has both the fixating materials and drug carriers [15]. The controlled drug capacity gets released via the diffusion from the cement through the dissolution of the apatite material. The bone cement will have less in vitro solubility than the typical block hydroxyapatites [22]. Probably, HA is used in delivering the skeletal drug system in the diseased bone. The oral therapeutic system has more acid in the gastric environment which can degrade its structure [22-24].

HA application has several problems in medicine. The use of HA as an Implant has inherent defects and fine porosity that could act as a crack initiator. In the event, the crack propagation can cause catastrophic deterioration during the application. More bulk of HA application sometimes will cause the mismatch between the implant and bone which will later cause the disproportionate load sharing. On the other side, the HA will always contain a trace of elements such as Fluoride ions (F-) and Hydroxyl ions (OH-). These fluoride ions and hydroxyl ions will cause an increase in crystallite size and a decrease in solubility which can increase the appetite strength. Few elements such as phosphide ions (PO3 3-) and chloride ions (CL-) have been known to decrease the Hydroxyapatite mechanical properties which cause the reduction in crystalline size and an increase in solubility [25].

Another problem that occurred by using HA in the application is to fine-tune the degradation rate. An HA-based implant will have poor mechanical properties which can induce not only fast degradation but also implant failure and chronic inflammatory reaction. For bone regeneration, the high calcium which is produced naturally is more important. Nevertheless, when the degradation occurs too fast the structural collapse of the implant may occur and induce too much graft resorption. For tissue regeneration, HA degradation is more important for the implant. Regarding this HA condition, the controlled release of HA particles can be carried out by manipulating the particle size. The particles which are small have a wider surface than large sizes with the same weight. The particle which has a smaller size will be easy to detach from the implant body [26-29].

Conclusion

HA is the most commonly used material in dentistry. This Hydroxyapatite coating on metal implants intensifies osseointegration in the early stage of bone healing. The HA on metal implants provides a strong bone-bonding capacity. While the titanium implant will also have the same level of bone contact in the later stage of healing. There is no significant coating over the influence of bone formation and bone-bonding strength through the crystallinity of HA. Among all, the HA coating has higher crystallinity which is more desirable in providing good strength, durability, and osteoconductive properties. In the future, it is reasonable to assume that hydroxyapatite and vitamin K2, vitamin D, chitosan-coated titanium dental implants may have better biocompatibility and osseointegration properties and hence, it is of interest to prepare titanium dental implants coated with nanohydroxyapatite and Vitamin K2 and to study their biocompatibility and osseointegration.

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