Hydroxyapatite as bone graft material - A narrative review.

Kumari Preity[1],Shiney Boruah[2], V Vidyashree Nandini[3].

[1]Intern, SRM Kattankulathur Dental College and Hospital.
[2]Senior Lecturer, Department of Prosthodontics and Implantology, SRM Kattankulathur Dental College and Hospital.
[3]Professor and Head, Department of Prosthodontics and Implantology, SRM Kattankulathur Dental College and Hospital.

ABSTRACT

Objective: This article examines and conducts a critical comparison of various studies regarding application hydroxyapatite as a graft material in various regenerative and reconstructive technique to promote bone formation following surgical procedure.

Background: In dentistry, bone graft is a widely used in regenerative technique to promotes bone formation. The main function of bone grafts is to provide mechanical support and to stimulate osteo-regeneration, with the ultimate goal of bone replacement. Though bone grafts are used extensively, there is lack of a concise knowledge-base on the application of hydroxyapatite graft material.

Methodology: English based literature online and offline, published from 2000 to 2023 is considered to obtain information. This has been analysed and scripted in a contextual manner.

Results: An analysis of available literature reveals that Hydroxyapatite has several advantages in tissue regeneration including minimal donor morbidity, improved biocompatibility, and lack of toxicity.

Conclusion: Hydroxyapatite is a suitable bone substitute material for bone reconstruction, with outcomes similar to that of conventionally used graft materials.

Application: Hydroxyapatite bone grafts are utilized for maxillary sinus floor augmentation following implant placement, periodontal defects, guided bone regeneration, socket preservation and alveolar ridge preservation.

Keywords: Alveolar bone loss, hydroxyapatite, regenerative technique.

Address of correspondence: Dr V Vidyashree Nandini MDS., DNB., Professor and Head, Department of Prosthodontics and Implantology, SRM Kattankulathur Dental College and Hospital, SRM Institute of Science and Technology, Potheri 603203, Chengalpattu Dist, Tamil Nadu, India.
Email address: - vidyashv@srmist.edu.in **Phone no:** 9444901719.
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Introduction

A bone graft is defined as a tissue material that have ability to repair and regenerate bone after embedded into a bony defect. In recent years the application of bone grafts has widely increased due to advancements in dental implantology and the growing need for repair of bony defects arise from trauma, periodontal disease, surgical excision, cranioplasty, infection or congenital malformations, and oral cancer.[1] The principle concept behind bone grafting is to anticipate mechanical support and to induce bone regeneration.[1]

The success of bone graft depends on four properties which include ,osteointegration, osteoconduction osteoinduction and osteogenesis. osteointegration facilitate chemical bond to surface of bone without formation of fibrous layer. Whereas osteogenesis facilitate regeneration of new bone within graft material. Osteoconduction produce scaffolds that's allow host cell to proliferate and facilitate migration of osteoblasts and vessels to osteomatrix. Osteoinduction retains the host stem in grafting site and differentiate this stem cells to produce osteoblast for formation of new bone.

Bone grafts can be classified as Autografts, allografts, xenografts, and alloplasts. Autogenous bone grafts are derived from the same individual, whereas allogenic bone grafts are typically derived from cadavers and are frequently accessible in a demineralized, freeze-dried state. Furthermore, non-human sources such as equine, porcine, and bovine bone are used to create xenogenic bone grafts. Alloplastic bone grafts made from mineral raw materials like tricalcium phosphate and hydroxyapatite (HA) are the most widely used type of bone graft.[2] Autogenous bone graft is still considered as gold standard because of its osteoconduction and osteoinduction nature but autogenous bone graft induces the risk donor site morbidity. In addition, Allografts and xenografts induces the risk disease transmission and can evoke an stimulate immunologic reaction. [2,3] To overcome this problems use of alloplastic grafting materials are becoming more popular. Alloplastic graft materials are synthetic bone substitute that are similar to natural bone.[1] Most commonly used synthetic bone grafts are tri- calcium phosphate and Hydroxyapatite and has been extensively used for regeneration of bone defect in craniofacial area. Tri- calcium phosphate are porus in nature and are mechanically weak due to faster rate of resorptions compare to hydroxyapatite that resorb less and retained large segmental block.[4]

Hydroxyapatite

Hydroxyapatite bone graft substitute is in great demand due to its superior hardness and osteoconductive nature.[5] Hydroxyapatite is a main constituent of bone and teeth. It contains 38% calcium and 18% phosphorus with ca/p ratio of 1.67.[6] however chemical of Hydroxyapatite bone graft substitute will be similar to inorganic elements of bone.[1] Hydroxyapatite graft material is available as:

1. Ceramic hydroxyapatite
2. Porous hydroxyapatite
3. Coralline hydroxyapatite
4. Nanocrystalline hydroxyapatite.

Ceramic hydroxyapatite

Hydroxyapatite ceramic are bioceramic [$Ca_{10}(PO_4)_6OH_2$] that contain calcium phosphate and are not present in human Hydroxyapatite. Ceramic Hydroxyapatite can be natural or synthetic. Synthetic Ceramics Hydroxyapatite facilitate a framework for deposition of new bone and form high density structure compared to the other forms of hydroxyapatite. However, the application of Ceramic hydroxyapatite is questionable due to poor mechanical property and is not indicated for load bearing. In past few years many dopping techniques has been employed to improve the mechanical and cytocompatible properties of Ceramic hydroxyapatite.[4] It consist of two crystallographic form.[1]

1. Tricalcium phosphate ceramic
2. Biphasic calcium phosphate ceramic

Tricalcium ceramic:

Tricalcium ceramic contain lower concentration of calcium phosphorus which results in faster biodegradation and absorption. Tricalcium ceramics exhibit superior osteoconductivity, resorbability, radiopacity and minimal risk for transmission of disease and immunogenicity. Tricalcium ceramics are ideal for reconstruction of periodontal and periapical defect.[1]

Biphasic calcium phosphate ceramics:

Biphasic calcium phosphate ceramics was developed to overcome drawback associated with Hydroxyapatite such as osteoconductivity and resorbability. The application Biphasic calcium phosphate ceramics in combination with hydroxyapatite enhance the mechanical property and lead to rapid bone formation. Biphasic calcium phosphate ceramics are most commonly used for periapical surgeries.[1]

Porous hydroxyapatite:

The porous hydroxyapatite produces superior results in terms of integration due to direct bonding between bone and graft material. The porous nature of the hydroxyapatite is due to partial conversion of tricalcium phosphate to hydroxyapatite when it is implanted in body. However, due to porous structure hydroxyapatite is brittle in nature and are contraindicated in loading sites. Hence porus hydroxyapatite are indicated bone defects result from trauma, tumour and cyst removal.[4]

Coralline hydroxyapatite

Coralline hydroxyapatite (CHA) is bone graft substitute that is used to fill bone voids. The hollow structure and biomechanical properties of Coralline hydroxyapatite (CHA) resemble cancellous bone. It anticipates the osteoconductive matrix needed for bone ingrowth as well as the structural integrity needed to support an articular surface. Coralline hydroxyapatite (CHA) is clinically recommended for both load bearing and non-load bearing areas.[4]

Nanocrystalline hydroxyapatite

Nanocrystalline hydroxyapatite are tiny particles with large surface area, that results in rapid resorption of bone and replace with vital bone.[7] Nanocrystalline hydroxyapatite resembles natural hydroxyapatite found in bone. Nanocrystalline hydroxyapatite is used for the reconstruction of periodontal defect and implants with successful outcome.[8]

Advantages of Nanocrystalline hydroxyapatite are

1. It has excellent bone integration
2. Nanocrystalline hydroxyapatite form more osteoblastic and osteoclastic cells compared hydroxyapatite
3. It has superior bio affinity.
4. Because of their shorter particle lengths, nanomaterials provide advantages in terms of location-volume ratio, effective surface area, and material stiffness

Preparation of Hydroxyapatite graft material:

Dry Technique

In dry technique calcium and phosphorus are mixed together in a dry environment to form hydroxyapatite. It is of two types solid state and mechanicochemical method. Solid state involves grinding and calcining of calcium and phosphorus to form hydroxyapatite. Whereas mechanochemical method use ball or planetary milling at a particular speed or frequency followed by diffusion process.[6]

Wet technique:

The term "wet methods" describes the synthesis of Hydroxyapatite using aqueous solutions. Most commonly used methods in Wet techniques comprises of chemical precipitation, hydrolysis, and hydrothermal methods. The average size and shape of the powder can be regulated using wet approaches. However low processing temperatures cause hydroxyapatite to exhibit low crystallinity.[6]

High Temperature:

Hydroxyapatite can be produced using high-temperature techniques that cause decomposition of material at high temperatures. High-temperature technique comprises of two methods pyrolysis and combustion. In combustion method Exothermic reaction is initiated by heating the mixture to a lower temperature and then abruptly heated to a higher temperature followed by rapid cooling. However, in pyrolysis method a precursor material is sprayed into a heated area of an electric furnace.[6]

Available as:

Pore structure: Porus hydroxyapatite can be prepared by breaking down hydrogen peroxide to create a structure filled with pores or by mixing calcium phosphate powder with naphthalene particles.[4]

Powder form: To prepare hydroxyapatite powder, isopropyl alcohol is combined with calcium carbonate (CaCO3) and dicalcium phosphate (DCPA) and then pulverized in a ball mill after being dried in a drying oven.

Block form: To prepare hydroxyapatite blocks, Tetracalcium phosphate (TTCP) and Dicalcium phosphate (DCPA) were weighed to determine the Calcium to phosphate (Ca/P) mole ratio. The two materials were then combined in a mortar and pestle, followed by deionized (DI) water.

Paste form: The prepared paste, consisting of tetracalcium phosphate - dicalcium phosphate (TTCP–DCPA) particles mixed with nitrogen-gas-bubbled deionized water at a mass-to-volume ratio of powder to liquid (P/L), was then crushed using an axial hydraulic press and deposited in a teflon mould. This was followed by heating the mixture in a muffle furnace.[9]

Application:

Maxillary sinus floor augmentation (MSFA)

Hydroxyapatite has been used as a successful graft material for maxillary sinus floor augmentation. The most distinctive feature of Hydroxyapatite is its sponge-like structure compared to other graft material that are granular. Due to its sponge-like structure hydroxyapatite material can be easily compressed into any available place for MSFA since it can be pinched using forceps and resist tearing of the sinus membrane. Ohba S, in his study used hydroxyapatite for maxillary sinus floor augmentation and evaluated its efficacy and safety for maxillary sinus floor augmentation. Author concluded that there were no signs of infection in his study, and application hydroxyapatite reduces the risk of postoperative infection. Furthermore, hydroxyapatite promotes the development of mature bone due to its suitable pore size for cell migration. Because of these features, hydroxyapatite is appropriate graft material for MSFA.[10] Studies have also shown that maxillary sinus floor augmentation with Hydroxyapatite allow immediate implant placement with good survival rate.[11]

Socket Preservation:

Socket preservation technique was developed to preserve the volume of alveolar bone by packing the extraction socket with Bone graft substitute. Past many years Hydroxyapatite has been used as a successful material for socket preservation due to its osteoconductive nature and its ability to form direct bond between graft material and newly formed bone. Several studies have been performed to evaluate the effectiveness of various hydroxyapatite in socket preservation. Dennissen et al. in his study used non- porus hydroxyapatite in socket preservation and found that the graft material was stable for 11years with direct bonding to the bone. Checchi et al, used nanostructured hydroxyapatite and conventional hydroxyapatite graft material in a fresh extraction socket and compared the histological and clinical radiograph. He concluded that both the materials are same in terms of bone regeneration, resorption and healing period. Apart from that, attempts have been made to use eggshell-derived nano-hydroxyapatite, which demonstrated optimal bone regeneration.[12] Therefore In socket preservation methods, hydroxyapatite presents itself as a potentially viable alternative material for bone regeneration.

Dental Implants:

Tooth replacement using dental implants has proven to be successful. However, in some clinical conditions, implant placement may be challenging because of a large bone defect. which allows implant treatment only after bone reconstruction using some bone grafts. Hydroxyapatite is a promising material for various dental treatments. it can be used as a bone graft substitute and as a coating material also. Due to its superior osteogenesis, osseointegration, bone induction property hydroxyapatite is most widely used bone graft substitute. However, hydroxyapatite exhibits low fatigue and fracture strength which is a limitation for its use in load bearing areas. To overcome the drawback hydroxyapatite has been used to coat metal which in addition have combine the superior biological properties of hydroxyapatite and Superior mechanical properties of metal to improve the outcomes. Hydroxyapatite deposited on the surfaces using Various method such as plasma spray, sol gel method, vapour deposition, dynamic mixing, electrophoresis. The dental implant coated with hydroxyapatite exhibit better bone regeneration properties compare to independent bone graft. [6,13] Doi K et al designed a unique complex made up of dental implant fixture surrounded by a block of hydroxyapatite. The complex was implanted into the bone Socket femur bone in animals and was evaluated at 2, 3 and 6 months. He concluded that these complexes have achieved for bone formation and implant stability.[14]

Periodontal Bony Defect:
Chronic periodontal disease led to alveolar bone destruction that results in formation of infra-Bony defect which need long term care and are clinically very challenging. Reconstruction of theses bony defect is commonly done through guided tissue Regeneration using barrier membrane and Guide bone regeneration (GBR) using hydroxyapatite graft materials as a successful treatment option is for reconstruction of bony defect.[15] Kamboj et al. assessed the effectiveness of hydroxyapatite bone graft in treatment of bony defects and concluded that Hydroxyapatite has a significantly improved attachment level and reduced the pocket depth reduction. According to Bansal et al, the use of nano-hydroxyapatite improves radiographic and clinical parameters during reconstruction. Hydroxyapatite can be considered as an alternative for autogenous bone graft in periodontal tissue regeneration. Recently hydroxyapatite has been used more frequently to its low toxicity and biocompatibility.[16]

Alveolar ridge Preservation:
Ridge resorption following extraction may result inadequate bone volume and height post extraction resorption preservation of Alveolar Ridge can be performed using various bone graft substitute. The hydroxyapatite bone substitute has been frequently used for preservation of Alveolar Ridge due to its high resistant to physiologic resorption. Kijarton P et al, Compared the efficacy of nano-porous hydroxyapatite and nano-crystalline bone graft for reservation of alveolar ridge before implant placement and concluded that ridge resorption was decreased and integration was enhanced with nano-porous hydroxyapatite.[17]

Conclusion
Hydroxide can be a permissible graft material for reconstruction of bony defect result from chronic periodontitis, tumor, cyst and trauma due to its osteoconductive, Osteoinductive, biocompatibility, non-inflammatory and non-toxic properties however hydroxyapatite has poor mechanical properties and is contraindicated in load bearing area. Due to this reason hydroxyapatite is also used as a coating material to coat implant which in addition can enhance the osseointegration of dental implant to the bone. To further improve the properties of Hydroxyapatite future research can include incorporation of physiologically active elements collagen and

cell growth factors onto the hydroxyapatite surface for use as bone grafting material. Furthermore, it is possible to anticipate the role of a drug carrier that hydroxyapatite alone could not represent by combining drugs with HA on the surface of metal or ceramic implants.

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