The journal of
PROSTHETIC AND IMPLANT DENTISTRY
Official Publication of Indian Prosthodontic Society
Kerala State Branch

BIOCERAMICS: DENTAL IMPLANT BIOMATERIALS

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Abstract:

Bioceramics are an important subset of biomaterials which act as an excellent bone substitute which is been used in many fields of medicine. Bioceramics range in their biocompatibility from the ceramic oxides, which are bioinert, to the other extreme of bioresorbable materials, which are eventually replaced by the body after they have assisted the repair of cells. Its application in dental implants has gained interest in the past two decades. This review is attempted to emphasize the approaches done in bioceramic materials for use in dental implants.

Keywords: Bio ceramics, zirconium, bioimplants

INTRODUCTION

The efforts to restore completely and partially edentulous arches have been practiced by clinicians since centuries. By the introduction of dental implants it has become the mainstream practice and is clinically accepted as the desired treatment modality for the patients. Implant biomaterials, especially bioceramics have provided the research and dental clinical professionals with a new essence of interest for over past two decades.

Biomaterial by definition is a "non-drug substance suitable for inclusion in systems which augment or replace the function of bodily tissues or organs." Bioimplants are prosthesis made for regularising the physiological function of body and bioceramics represent one classification of the bio implant based on the material used.

HISTORY

Plaster of Paris ($CaSO_4.H_2O$) – first widely evaluated bioceramic

1892—Dressman published first report on the use of plaster of Paris to repair bone defect.

1920—first successful use of Tricalcium phosphate

1930—polymeric implants introduced (Rock 1933-alumina)

1960s—1970s – interest in bioceramic invention by work of Hulbert and co-worker.

1969-1971—bioactive glass ceramic first introduced by L.L Hench.

1988—plasma sprayed hydroxyapatite first used by Herman

IMPLANT BIOMATERIAL SELECTION GUIDELINES

The American dental association outlines some acceptance guidelines for dental implant biomaterials:

1. The evaluation of physical properties that ensure sufficient strength;

2. Demonstration of ease of fabrication and sterilization potential without material degradation;

3. Safety & biocompatibility evaluation, including cytotoxicity testing & tissue interference characteristics;

4. Freedom from defects;

5. At least two independent longitudinal prospective clinical studies demonstrating efficacy.

CLASSIFICATION OF BIOCERAMICS

Ceramics used for the repair and reconstruction of diseased or damaged parts of the musculoskeletal system termed as bioceramics, maybe categorized as follows:

1. Based on tissue reaction

BIOACTIVE	Material which upon being placed within the human body interact with surrounding bone and soft tissues.	Eg: Synthetic hydroxyapatite, bioglass, apatite-wollastonite glass ceramic.
BIOINERT	Material once placed in the human body has minimal interaction with its surrounding tissue.	Eg: Titanium, zirconia, alumina, stainless steel, carbon and carbon silicon compounds
BIORESORBABLE	Material upon placement with the human body starts to dissolve and slowly replaced by advancing tissue(bone)	Eg: Tricalcium phosphate, polylactic-polyglycolic acid copolymers, calcium oxide, calcium carbonate and gypsum

2. Based on tissue attachment

1. Morphologic fixation	2. Biological fixation	3. Bioactive fixation	4. Bioresorbable
Dense, non-porous, nearly inert ceramics that attach by bone growth into the surface irregularities. It can be either cementing into tissue /press fitting into a defect.	Porous inert implants has bone ingrowth which mechanically attaches bone to material	Dense, non-porous, surface reactive ceramics, glasses and glass-ceramics attach directly by chemical bonding with bone.	Dense, non-porous or porous resorbable ceramics are designed to be slowly replaced by the bone.
Eg: aluminium oxide(single crystal and polycrystalline)	Eg: aluminium oxide (porous polycrystalline), Hydroxyapatite coated porous metals	Eg: bioactive glass, bioactive glass-ceramics, Hydroxyapatite	Eg: calcium sulphate, tricalcium phosphate

BIOACTIVE CERAMICS

Bioglass / Glass Ceramics:

Discovery of Bioglass was by Hench and Wilson. It was first introduced in the year 1971. The glasses containing specific proportions of silica, sodium oxide, calcium oxide and phosphorus pentoxide are termed bioactive. The nucleation and growth of crystals within the glass converts the glass to glass ceramics, which retain the bioactivity. They have high mechanical strength, fast setting ability, low resistance to tensile and bending stresses and extreme brittleness. They chemically bond to bone due to formation of calcium phosphate surface layer. Ceravital silica a type of glass ceramic.

Hydroxyapaptite:

It is chemically calcium phosphate [Ca_{10} $(PO_4)_6$ $(OH)_2$]and is similar to the mineral component of bones and hard tissues. Hydroxyapatite was successfully used as an implant material in 1988 soon after the bioactive glasses were developed. The hydroxyapatite in powder form is excellent bone filler. They have calcium to phosphorus ratio of 1.67 and is the most stable phase of various calcium phosphates. The preparations of hydroxyapatite powders include wet methods and solid state reactions. Hydroxyapatite is stable in body fluid and in dry or moist air upto 1200^{0}C and does not decompose.

Plasma sprayed hydoxyapatite was first used by HERMAN in 1988. It is used as coatings on implants.

BIOINERT:

Alumina:

Alumina is a highly inert material which was introduced by Rock in 1933. It was first used as an implant material in the 1970s. It has excellent wear resistance and surface hardness. Alumina exists in many forms and these arise during the heat treatment of aluminium hydroxide or aluminium oxy hydroxide. However the body recognises it as a foreign material and attempts to isolate it by forming a non adherent fibrous layer which is considered as a drawback in the use of this material.

Titanium:

Titanium was first introduced in the year 1789 by Wilhelm Gregor. Due its excellent property of biocompatibility and its ability to form stable oxides it has been successfully used as an implant material in the recent years. Three different oxides formed on titanium surface are TiO (Anastase), TiO_2 (Rutile) and Ti_2O_3 (Brookite).

Titanium oxide layer exhibits low level of charge transfer. Its modulus of elasticity of is half of the other alloys 5 to 5.6 times greater than bone that helps in its uniform stress distribution.

Zirconia:

Zirconium dioxide was first extracted from the mineral Zircon (Zirconium Silicate $ZrSiO_4$) by the German chemist Martin Heinrich Klaproth (1743-1817). It was in 1969 the first scientific study of outstanding biomedical properties of zirconia emerged and subsequently it was found that alloying zirconia with oxides of yttria, calcia and magnesia made it stable. This discovery also led to the use of the so-called transformation toughening of zirconia to produce ceramics with unsurpassed crack resistance ('ceramic steel').

Zirconia was successfully used as implant material in 1960s. It has high flexural strength, fracture toughness and ability to be polished to a superior surface than alumina. Zirconia implants also absorb water and hence become prone to fracture.

Yttrium stabilised tetragonal polycrystalline zirconia:

This form of zirconia offers best mechanical properties.

Carbon and carbon silicon compounds:

Vitreous carbon and carbon compounds are used in implantology since 1970. Carbon is a versatile

that exists in many forms. The biocompatibility of carbonaceous material to bone indicates its use in orthopaedic implants. However due to the intrinsic brittleness and low tensile strength, carbon compounds have limitations for use in major load bearing applications.

BIORESORBABLE:

Calcium phosphate ceramics:

Calcium phosphate ceramics was first commercially used as implant material in 1980s. They have biochemical composition similar to bone and exhibit direct chemical bonding to surrounding bone. Therefore they are used as implant material to be gradually substituted by newly formed bone and get integrated with the host bone. The first stage is interaction with collagen in bone and then accumulation of protein and cells on the surface of the biomaterial and this is followed by the resorption of the material and finally bone formation.

A subclass of these ceramics is tricalcium phosphate ceramics. They are extensively used owing to its biocompatibility characteristics. They also have an added advantage of being resorbable.

Other calcium phosphate compounds include:

-Amorphous calcium phosphate (ACP)

-Dicalcium phosphate (DCP)

-Pentacalcium hydroxyapatite

-Tetracalcium Phosphate Monoxide (TTCP)

NEW DEVELOPMENTS IN BIOCERAMIC IMPLANT MATERIALS:

Titanium-Zirconium alloy (*Straumann* ROXOLID)

Narrow diameter implants (Roxolid®, Straumann, Basel, Switzerland) has recently been introduced in dentistry. This alloy which has a metallic gray appearance contains 83-87% titanium and 13-17% zirconium. It has superior mechanical characteristics over commercially pure (CpTi) and Ti-6Al-4V, as well as increased fatigue strength.

The addition of zirconia to titanium leads to excellent osseointegration capabilities. The biocompatibility of titanium-zirconium alloy is also more when compared to pure titanium.

In order to maintain the clean oxide layer with its hydrophilic properties the Titanium-Zirconium implants are manufactured with the SLActive surface like the titanium SLActive implants: Sand blasted, acid etched and then stored in 0.9% NaCl solution.

Polyetheretherketone (PEEK)

For patients with high aesthetic requirements, the new material known as PEEK (polyether ether ketone) is recommended as it is aesthetic, stable, biocompatible, lighter degree of discoloration. BioHPP (High Performance Polymer) is based on polyether-ether-ketone (PEEK) polymer and was introduced as dental material for precise prosthetic restoration fabrication. BioHPP has a low specific weight that permits the fabrication of lighter prostheses which provides high patient satisfaction and comfort during masticatory function.

BioHPP reduces the stress caused by natural forces as well as the forces attributed to the prosthetic restorations. While comparing with titanium, zirconium or ceramic, rehabilitation using BioHPP significantly reduces the peak masticatory forces both for axial and oblique movements. This property provides a positive effect for the patient and also it extends the durability of the restoration.

Silicon nitride (Si_3N_4) ceramics

Titanium has been the choice for dental implant

fabrication for many years owing to its superior mechanical and biological performances. The increasing demand for metal-free restorations has led to development of ceramic-based implants like Zirconia and other alternative biomaterials like PEEK and silicon nitride.

Silicon nitride has following properties:

- Excellent antibacterial properties
- Biocompatible and biologically inert
- High flexural strength
- High fracture resistance
- Excellent wettability to biologic fluids
- High wear resistance

Silicon nitride derives its strength and toughness through its microstructure, which is mainly composed of asymmetric needle-like interlocking grains surrounded by a thin (<2mm) refractory grain-boundary glass. Unlike other ceramics, there is no phase transformation is involved.

CONCLUSION

The primary requisite for a dental implant material is to be biocompatible and have superior biomechanical properties. Various implant biomaterials like titanium, zirconia, etc are used in this aspect which provides excellent osseointegration with the bone. The recent developments in biomaterials having high esthetic performance like polyetheretherketone and silicon nitride have given way for more future research which could be of great interest for oral use.

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