

Biomaterials in implantology: A review

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Abstract

Biomaterials used in implantology have evolved over a period of time. In quest for desirable mechanical, physical and biological properties of material, numerous modifications have been made in existing materials. In order to optimize acceptance of implant in the biologic environment constant efforts have been made to introduce new materials or to improve existing material properties. It is imperative for every clinician to be thorough with the recent advancements and newer biomaterials so as to effectively select a material. For years titanium has ruled over other biomaterials and been used successfully as a dental implant material due to the excellent biocompatibility that it offers. This article makes an effort to summarize various dental implant biomaterials which have been used over a period of time now.

Keywords: Biomaterials, Implantology, Roxolid.

Introduction

Edentulism whether partial or complete, has been over a period of time treated with various treatment modalities. Patient's constant desire for a fixed prosthesis has almost always posed as a challenge before the clinician. Amongst various modalities implantology emerged as a milestone in long term preservation of residual ridge and health of adjacent teeth. Being the closest replacement to natural teeth, implants have been successful in providing the desired retention and fulfilling patient's preference for a fixed prosthesis over a removable one.

Ever since ancient Egyptians used gold ligature wires in 2500 BC to Dr. Hunter's experiment to transplant human teeth from one into another in 1700's to modern day practice implantology has improved manifolds.¹ Tireless researches have resulted in the improved properties of implant materials thereby instilling clinician confidence and patient's preference in this treatment modality. The seminal research carried out by Branemark and his coworkers in the quest for replacing molars with 'titanium roots' and since then titanium has ruled this field for the excellent properties it exhibits. Newer materials such as zirconia, surface modified titanium implants fulfill functional requisites as well as exhibit an esthetic superiority over conventionally used implants. This article reviews and summarizes various implant materials and their properties.

Properties of Implant Materials

Bulk Properties^{1,2}

Strength: Functional stability is a factor dependent on high values of tensile and compressive strength. High strength of the material would help in prevention of fractures and transfer of stress from implant to bone improves significantly. Similarly, high yield strength

and fatigue strength values are also important so as to prevent breakdown under cyclic loading.

Modulus of Elasticity: Elastic modulus of compact bone has been reported to be 18 GPA. An implant must exhibit a similar modulus so as to be considered suitable. This prevents stress concentration at the implant site as well as minimize any relative movement at implant-bone interface.

Ductility: ADA suggests that minimum ductility of 8% is required for dental implant. Ductility is a property that renders shape and contour to the implant.

Surface Properties

Surface Tension and Surface Energy: Wettability of implant surface depends on surface tension and energy. This property enables the fluid (blood) to wet the implant surface which helps in maintaining cleanliness of the same. Surface energy also affects adsorption of proteins.

Surface roughness: Increasing the effective surface area by means of inducing roughness allows osteoblasts to act upon the surface and initiate cell attachment.

Biocompatibility: A favorable response of body tissues to implant is the most important property of implant material in given biological environment. It is largely dependent on the corrosion resistance exhibited by the material and cytotoxicity of corrosion byproducts so formed.

In reactive group metals such as titanium, niobium, zirconium, tantalum, it is the nature of base material that governs formation of oxide layer. As suggested by Williams,³ three types of corrosion have been explained:

Stress Corrosion cracking: This occurs when high mechanical stress occurs in presence of corrosive environment resulting in failure of metallic materials by cracking.

Galvanic corrosion: When two dissimilar metallic materials come in contact in presence of an electrolyte can result in flow of current between the two.

Fretting corrosion: This type of corrosion is observed when a micromotion and rubbing contact occur simultaneously within a corrosive environment. It has been reported to occur along implant body-abutment-superstructure interfaces.

Biomaterials: The synthetic biomaterials have been classified metallic, ceramic and surface-modified (coated, reacted or ion-implanted) groups.

Metals and Alloys

Titanium and Titanium-6 Aluminium-4 Vanadium (Ti-6Al-4V): Titanium has a property to get readily oxidized in presence of room temperature air and tissue fluids, also known as passivation. This property is found to be favorable for dental implant devices. Studies^{4,5,6} have suggested use of titanium as a material of choice owing to its inert and biocompatible nature along with excellent resistance to corrosion. With a low elastic modulus (97 GN/m²) and tensile strength (240-550 MN/m²) when compared to other alloys strength of this material has been recorded to be approximately 1.5 times greater than the strength of compact bone. Most commonly used alloy of titanium is titanium-aluminium-vanadium. And almost six times stronger than compact bone. Mechanically titanium is much more ductile than titanium alloy.

Cobalt-Chromium-Molybdenum-based alloy (Vitallium): Most often used in cast and annealed metallurgical condition. This permits fabrication of implants as custom designs such as subperiosteal frames. Cobalt provides continuous phase for basic properties, carbon makes the alloy four times stronger than that of compact bone and also offers resistance to surface abrasion. On the other hand, chromium forms an oxide layer which provides corrosion resistance and molybdenum provides strength and bulk corrosion resistance.

Iron-Chromium-Nickel-based alloy: These alloys are known to exhibit galvanic potentials and when used in conjunction with materials like titanium, cobalt, zirconium or carbon implant biomaterials, galvanic coupling might result. Biocorrosion may also be one of the consequences.^{7,8,9}

Iron based alloys used commonly for ramus blade, ramus frame, and some mucosal insert. This alloy may readily undergo pitting corrosion. Care must be observed to retain the passivated (oxide) surface condition, as this alloy contains nickel as a major element. Also patient with a documented history of nickel allergy must be avoided.¹⁰

Ceramics and Carbon: Ceramic oxides were introduced to be used for surgical implant devices as they exhibited inertness to biodegradation, high strength, physical characteristics such as color and minimal thermal and electrical conductivity and a wide

range of material specific elastic properties. Recently use of ceramics has been propagated in bulk as well as in the form of coatings on metals and alloys.

Aluminium, Titanium and Zirconium oxides: High-strength ceramics from aluminum, titanium and zirconium oxides have been used for root form endosteal plate form and pin type of dental implants. Strength has been reported to be three to five times that of compact bone. Also as they provide an esthetic superiority they are highly indicated for applications such as anterior root form devices. Zirconia exhibits polymorphism and monoclinic, cubic and tetragonal are the three crystal forms in which it exists. Monoclinic form exists at room temperature. This enters into tetragonal phase at around 1170°C, followed by a cubic phase at 2370°C. However at room temperature these phases are not stable and break into pieces, on cooling. Addition of oxides like that of calcium, magnesium, yttrium can help in stabilization of the cubic phase of pure zirconia thereby resulting in formation of a multiphase material called partially stabilized zirconia (PSZ). Yttria stabilized TZP possesses low porosity, high density, high bending, and compression strength and is suitable for biomedical application.¹¹

Titanium-zirconium alloy (Straumann Roxolid): Addition of 13%-17% zirconium to titanium results in formation of an alloy TiZr1317 with better mechanical properties like improved fatigue strength than that of pure titanium. Straumann introduced Roxolid that is 50% stronger than pure titanium. Sandblasting and acid-etching on, TiZr1317 with a monophasic a structure resulted reproduction of a surface topographically identical to that of pure titanium implants. Its superior mechanical properties enable use of thin implants and implant components in the areas of high strain.¹²

Bioactive and Biodegradable Ceramics based on calcium phosphate: Calcium phosphate ceramics (CPCs) are widely used in dental reconstructive surgeries. Its advantages include that chemistry mimics normal biological tissue hence exhibits excellent biocompatibility. There is minimum thermal and electrical conductivity. Esthetic superiority over conventionally used implants. However, there are certain disadvantages such as low mechanical tensile and shear strengths under fatigue loading, and variable mechanical stability of coatings under load-bearing conditions.

The calcium phosphate coatings are nonconductors of heat and electricity. This can provide a relative benefit for coated dental implants where mixtures of conductive materials may be included in the overall prosthetic reconstruction.

Carbon and Carbon Silicon compounds: Carbon compounds are also studied under ceramics as they are chemically inert and do not exhibit ductility. However, they are conductors of heat and electricity. Ceramic and carbonic substances are used as coatings on metallic

and ceramic materials. Mechanical strength properties along substrate-coating interface are compromised. Biodegradation may adversely influence the tissue stability. It also offers minimal resistance to scratching or scraping procedures associated with oral hygiene.

Polymers and Composites: Fiber-reinforced polymers offer advantages in that they can be designed to match tissue properties can be anisotropic with respect to mechanical characteristics, can be coated for attachment to tissues, and can be fabricated at low cost.

Structural Biomedical Polymers and Composites: The more inert polymeric biomaterials include PTFE (polytetrafluoroethylene) PET (polyethylene terephthalate) PMMA PP (polypropylene) PSF (polysulfone) etc. The indications for PTFE have grown exponentially for development of guided tissue regeneration techniques. However, PTFE does not have a high contact abrasion and wears easily.

Several inert polymers have been combined with particulate or fibers of carbon, Al₂O₃, HA and glass ceramics.

Surface modifications

Titanium plasma sprayed: Porous or rough surfaces have been created over machined smooth surfaces of titanium have been fabricated by plasma spraying a powder form of molten droplets at high temperatures. At temperatures in the order of 15,000°C an argon plasma is associated with a nozzle to provide very high-velocity 600m/sec partially molten particles of titanium powder (0.05-0.1 mm diameter) projected onto a metal or alloy substrate. Plasma-sprayed layer after solidification is often provided with a 0.04 to 0.05 mm thickness. Microscopically they appear as round or irregular pores connected to each other.

Hydroxyapatite coating: Degroot¹³ introduced spraying the coat of hydroxyapatite layer. It helps lower the corrosion rate of same substrate alloys and also accelerate bone formation and maturation around HA-coated implants. HA coating has also been credited with improved bone-implant attachment compared with machined surfaces.

Conclusion

The various implant biomaterials have evolved over a period of time and found significance in most of the implant related literature. Improvement in bulk and surface properties has helped us establish selection criteria for choice of implant. It is imperative for clinician to be well versed with these properties. Goal of modern dentistry is to understand and execute the benefits of biotechnology in health care.¹⁴

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