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A review on: materials for biomedical implants

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Abstract

The implant of biomaterial is a key factor for the long-term success of implants. The biological environment does not accept completely any material so to optimize biological performance; implants should be selected to reduce the negative biologic response while maintaining adequate function Synthetic materials for surgical implant devices have evolved from the early metallic systems to a variety of material combinations and composites. This article is an effort to review various biomaterials of implants that were used in the past and as well as the latest material used now. Further improvements in existing systems require a continuation of the multidisciplinary approach to the laboratory, experimental animal, and human clinical research.

Introduction

Biomaterial is defined as "A nondrug substance suitable for inclusion in systems which augment or replace the function of bodily tissues or organs." A universal criterion for a dental implant biomaterial is to achieve osseointegration with the bone. It was discovered in the year 1952 by Dr. Per Ingvar Branemark. He introduced threaded implant design constituting of pure titanium which achieved Osseo integration. As a wide array of implant biomaterials has been in use with different properties, it is the clinician who chooses the best which essentially influences the longevity of the implant.

Implants are traceable to early Egyptians and South Central American cultures and with all the developments in material and biological science we have come a long way. Improvements in both the quality and quantity of the implant material have made this treatment modality very promising, budding and highly practiced in today's era. The Earliest dental implants of stone and ivory were reported in China and Egypt. Also Gold and Ivory dental implants were reported in the 16th and 17th centuries [1].

The usage of implants and medical equipment's has become a popular practice and it is necessary to save the lives of thousands of people every day. For example, about one million hip replacements and more than 250,000 knee replacement surgeries are reported throughout the world every year [2]. Therefore, it is of significant interest to utilize widely the metallic implants to accommodate various surgery demands, both minimizing the patient discomfort and to achieving economic progress for the healthcare system, economic progress for the healthcare system. Biomaterials are the materials used for making devices that can interact with biological systems to coexist for long service with minimal failure. Williams (1987) defined biomaterials as "nonviable materials used in medical devices, intended to interact with the biological systems"

Metal Implants of Gold, Lead, Iridium, Tantalum, stainless steel and cobalt alloy were also mentioned in the early 20th century. Between these two periods a variety of polymers, including ultrahigh molecular weight polyurethane, polyamide, poly methyl methacrylate resin, polytetrafluoroethylene, and polyurethane, have been used as dental implant. In the present era, due to the extensive research work and advancements in the field of biomaterials available for dental implants, newer materials came into being such as zirconia, roxolid, surface modified titanium implants. These materials not only fulfill the functional requirements but are also esthetically pleasing. This article makes an effort to review various implant materials, their properties and the various pros and cons associated to those materials.

Materials for Biomedical Implants

Metals and alloys

- Titanium and its alloys
- Cobalt chromium alloys
- Austenitic Fe-Cr-Ni-Mo steel
- Tantalum
- Niobium
- Zirconia

Metals

The major medical industry segment relies on several metallic sections. Metals are generally used for load-bearing applications like plates, hip, pins, knee prostheses, screws, dental materials and maxillofacial cardiovascular surgery [3]. While metals have high durability and strength but they can degrade in the physiological condition contributing to the development of particulate material which in turn can trigger biological responses [5]. Most metallic alloys trigger metal ions in human plasma when surgically placed in the body.

On the long run, the conventional metals (gold, stainless steel, and cobalt-chromium) have become outdated and are now replaced by titanium (Ti) and its alloys (mainly Ti-6Al-4V) [1,6]. Titanium alloys are light, strong and highly resistant to fatigue and corrosion, six times stronger than compact bone and offer more opportunities for designs with thinner sections. When compared with Co-Cr-Mo alloys, titanium alloys are twice as strong and have half the elastic modulus. And also titanium shows a relatively low modulus of elasticity and tensile strength when compared with most other alloys [6].

Alloys:

Primarily, three categories of alloys predominate in these groups. They are stainless steel, Co-Cr alloys and titanium alloys. In India 304 and 316L stainless steels are the most commonly employed in biomedical applications due to their ease of manufacturing and low cost relative to the Ti and its alloys and Co-Cr alloys. The 316L and 304 SS have excellent corrosion resistance, tensile strength and appropriate load bearing density, making this material a suitable surgical-implant material. The presence of the stainless steel implants in the body's immune system contributes to the release of nickel and chromium ions which causes the allergic reactions [6].

Cobalt-chromium (Co-Cr) alloys have good corrosion-resistant properties but are not suggested for joint prosthesis due to weak frictional and tensile properties with other materials or with itself [7].

Titanium (Ti) and its alloys (Ti-6Al-4V, Ti-13Nb-13Zr, Ti-5Al-6Nb) have received considerable attention due to the fascinating mechanical properties such as fatigue resistance, more strength and superior biocompatibility. Moreover, in various fields such as osteosynthesis, oral implantology and joint prosthetics Ti alloys have exhibited their potential as an implant material. Presently used biomedical titanium alloys are categorized as α, near-α, α-β, stable α alloys and metastable β. These two particular alloys contain vanadium (V) and aluminum (Al) compounds that release toxic ions and produce adverse health effects. Vanadium causes cytotoxicity whereas neurological disorder (Alzheimer's disease) is caused by aluminium [8].

Ceramics

- Aluminium oxide (Al2O3)
- Zirconium oxide Hydroxyapatite (HA)
- Tricalcium phosphate
- Tetracalcium phosphate
- Calcium pyrophosphate
- Fluorapatite Brushite Bioglass etc.

Ceramics are inert to biodegradation and possess high strength and other physical characteristics suitable for implant application. Aluminium, titanium, and zirconium oxide have a clear, white cream or light grey colour that is beneficial for application on anterior root form devices. They have minimum thermal and electric conductivity, biodegradation, and reaction to bone, soft tissue, and oral environment are also considered to be beneficial when compared with other types of synthetic biomaterials. Materials made of Calcium phosphate (CaPO4) such as tricalcium phosphate (TCP) and glass ceramics have excellent biocompatibility, no local or systemic toxicity, minimal thermal and electrical conductivity, no alteration to natural mineralization process of bone, and lower mechanical, tensile, and shear and fatigue strength. Apart from the use as a bone substitute, calcium phosphates have been considered as a good option for implant coatings that may promote accelerated bone healing around implants.

There is an increasing interest in iron oxide (Fe_3O_4) particles as it has great potential for the biomedical applications. The Fe_3O_4 particles are considered for their known biocompatibility and super magnetic nature in multifunctional applications such as good dispensability, tissue engineering, anti-corrosion agent, chemically stable and biochemical processes. In the earlier study, it was demonstrated that the incorporation of Fe_3O_4 particles in HA phase can be desirable to enhance the biocompatibility, corrosion resistance and surface properties of the substrate.

The latest ceramic to be used as dental implant is zirconia (zirconium dioxide). It is found to possess good mechanical properties owing to its multiphase structure. The metastable tetragonal phase stabilized zirconia will displaya stressinduced transformation toughening mechanism. The strength and toughness of zirconia can be accounted for by its toughening mechanisms such as crack deflection, zone shielding, contact shielding, and crack bridging. Preventing the crack propagation is of critical importance in high-fatigue situations such as mastication and parafunction. This combination of favourable mechanical properties makes zirconia a unique and stable material for use in high-load situations [9].

Zirconia is radiopaque and clearly visible on radiographs. It's ivory colour, is similar to the colour of natural teeth and is especially critical in the aesthetic zone with high lip line smiles. Zirconia is also proposed to accumulate lesser plaque than titanium. Furthermore, with the development of dental computer-aided design (CAD) computer-aided manufacturing (CAM) systems, this high strength ceramic is gradually becoming a satisfactory implant biomaterial [10].

Polymers and composites

Polymeric implants in the form of polymethyl methacrylate (PMMA) and poly tetra fluoro ethylene (PTFE) were first used in the 1930s. Other types of polymers, which were used subsequently as dental implant material included polyamide, polyethylene (PE), polyurethane (PU), polypropylene (PP), polydimethyl siloxane, polysulfone (PS), and silicone rubber. In general, the polymers have lower strengths and elastic moduli and higher elongation to fracture compared with other classes of biomaterials. Most polymers have shown elastic modulus with magnitudes closer to soft tissue [10].

Polymers are the most widely used materials in biomedical applications. These are consists of large number of small repeating units called monomer. Polymers are mainly classified into biodegradable and non-biodegradable. Biodegradable polymers are polycaprolactone, poly lactide-co-glycolide, chitosan (CS), alginate, chondroitin sulfate and polylactic acid, whereas polyethylene terephthalate, polytetrafluoroethylene, polypropylene and polymethylmethacrylate are non-biodegradable polymers. Among the biodegradable materials, CS acts as a capping agent due to their remarkable properties such as wound healing activity, biocompatibility, biodegradability, antibacterial and environmental friendliness [15]. Polymers are primarily used for heart valves, contact lens replacements, kidney, pacemakers, skin, bone and artificial blood vessels. Due to mechanical and biochemical factors, the polymers undergo degradation in the body environment. Polymers have much lower strength and moduli as compared to ceramics, therefore polymers are not generally used for load bearing conditions such as knee and joint prostheses [16].

Composite materials are obtained by combining two or more materials capable of working synergistically to provide superior properties to those offered by single material [11]. Ceramics have excellent biocompatibility but weak mechanical properties, and thus these materials cannot satisfy the various requirements of safe and successful in vivo functioning. This turned the focus to bioceramic composites that could take the advantage of favorable properties of each composite material while diminishing the limited characteristics of each component. The excellent properties of composites like lightweight and mechanical strength enable them to use extensively for restoration and dental fillings, ligaments and bones. Composites consist of bioactive and bioinert ceramics are develop to attain two important characteristics such as bioactivity and mechanical strength [12].

Factors Responsible for the Performance of Biomaterials

Mechanical properties of biomaterials

The bio-implants are prone to complex service conditions and heavy loads in human body atmosphere. The implants experience both static and dynamic loads based on the patient's activity. The implants should have capable of transferring the loads and activities arising from the repair of damaged joints and muscular movements.

Direct overloading

The purpose of using a fixation device is to maintain close contact with the ends of the broken bone so that healing is stimulated.

Wear

Wear is the mechanical extraction of materials between two or more interacting surfaces during the relative motion process. The wear of joint prostheses may be occurring by fatigue, abrasion, corrosion and adhesion.

Fatigue loading

Fatigue failure is defined as implant's failure which associated with the stress and dynamic cyclic loading. Fatigue cracks causes local stresses on the implant surface that arise within the elastic deformation range. Reportedly, the fatigue cracks are induced by corrosion and expanded mainly by fatigue mechanism.

Biocompatibility

The term "biocompatibility" signifies the potential to remain in contact with human body tissues without causing any damage to the body.

Tissue implant corrosion

Interaction between a material and its environment which leads to deterioration of mechanical and physical properties is termed as corrosion. The progressive materials degradation due to an electrochemical invasion is a major concern when the implant is inserted in the body's electrolytic environment.

Pitting corrosion

Pitting corrosion is the generation of small cavities on the material surface, due to the localized attack of corrosion which result in severe damage to the surface of material.

Fretting Corrosion

Fretting corrosion occurs due to repeated vibration and wearing on an irregular rough surface. It emerges at the interface of high loaded metal surfaces when prone to minor vibratory motions.

Surface Modification Techniques

An Overview During the last few decades, a sustainable work on HA coating have not only concentrates on tissue-coating interaction, but also on the issues associated with the coating methods and refinement of coating properties for optimum tissue response and minimization of corrosion.

Conclusion

The implant materials, their composition and properties are not gossiped about in most of the implant related literature. Different metallic alloys are used for bio-implantation. However, there still remains a challenge for the applications of metallic alloys as these are suffers from corrosion in the body environment. Various methods have been studied to enhance the corrosion protection of metallic alloys along with the enormous capabilities to obtain bioactive coatings with desirable surface morphology. In finally conclusion that, Implants have been gaining popularity amongst the patients and frequently are being considered as a first treatment option, a need for collaborative and multidisciplinary endeavours to eliminate holdups associated with the combination of engineering and medical fields for the creation of new generation biomaterials implants.

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