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An overview of dental implant biomaterials

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Abstract

Regardless of stomatognathic system atrophy, illness, or injury, modern dentistry endeavours to restore the patient to normal shape, function, comfort, aesthetics, speech, and health. Predictable success is now a reality for the rehabilitation of many difficult conditions as a result of ongoing research in treatment planning, implant designs, materials, and methodologies. The medical fields have long placed a strong emphasis on the biocompatibility properties of synthetic materials (biomaterials) used to replace biological tissues. In addition, implant biomaterials must be suitable in terms of mechanical strength, biocompatibility, and structural biostability in order to function at their best. In this article, the various implant biomaterials with their properties and applicability to implant dentistry are discussed.

Keywords: Dental implants, Endosseous implants, Transosteal implants, Sub-periosteal implants, Ceramics, Titanium, Polymer and Carbon compounds.

1. Introduction

Dental caries, periodontal diseases, trauma, and other diseases or risk factors, such as diabetes, hypertension, arthritis, smoking, and poor nutrition, are the most frequent causes of tooth loss. The missing tooth or teeth are frequently replaced by removable or fixed partial dentures. Another credible alternative for treating tooth loss or tooth replacement is using dental implants [1]. According to the glossary of prosthodontic terms-9, a dental implant is a prosthetic device that is usually made of alloplastic materials and inserted into the oral tissues underneath the mucosal and/or periosteal layer and on or within the bone to provide retention and support for a fixed or removable dental prosthesis; a substance that is placed into and/or on the jaw bone to support a fixed or removable dental prosthesis [2].

Civilizations in South-Central America, China, and Egypt used implants for a variety of purposes. Stone and ivory made up the majority of the earliest dental implants. Metal-based implants made of alloys of gold, iridium, stainless steel, lead, tantalum, and cobalt were utilised in the early 20th century. Due to recent improvements in biological and material sciences, technological advancements, and the quality and quantity of implant material, implant dentistry has grown in popularity [1,3-5]. The various dental implant materials and their properties are highlighted in this review.

2. Osseointegration

The success of the implant treatment majorly depends on the ability of the biomaterials that encourages the bone to grow on to its surface, usually termed as osseointegration. To be specific, osseointegration is the direct structural and functional connection between living bone and the surface of a load-bearing artificial implant [1,6,7]. For this to happen, the bone should be viable, the gap at the interface of the bone and implant must be less than 10 nm and there should not be any connective tissue at the interface [1,6-8]. The concept of osseointegration was introduced by a Swedish orthopedician, Per-Ingvar Branemark in 1969. He observed the formation of bone around the titanium chambers in the femurs of the rabbit [1,6,7].

3. Requirements of implant materials

An ideal implant material should be/have [1]

- biocompatible.
- promote osseointegration.
- chemically stable and should not undergo corrosion.
- able to withstand the masticatory stresses.
- Possesses mechanical properties similar to that of bone.
- Easily available
- inexpensive.

4. Types of implants

Subperiosteal, endosseous, and transosteal implants are the three types of implants that are categorised according to their placement.

4.1 Subperiosteal implants

These implant devices are essentially thin metal frameworks that rest on the bony ridge (Figure 1). The framework is most widely used in the atrophic mandible and usually made from cobalt-chromium alloy. However, these implants have short-term satisfactory results [1].

4.2 Endosseous implants

These types of implants are partially submerged and anchored within the bone (Figure 2). These implants have a higher success rate over 15 years than subperiosteal implants. Endosseous implants are available in a variety of designs, including blade, cylindrical, either with a nail-like or screw-like form [1].

4.3 Transosteal implants

Transosteal implant systems only function in the mandible and totally penetrate the bone (Figure 3). For the ridge augmentation approach, these implants are taken into consideration. According to numerous studies, these implants have a 90% survival rate during an 8–16 year span [1].

5. Implant materials

Four major types of materials, including metals and alloys, ceramics, polymers, and composites, are used to make dental implants (Table 1).

Table 1. Classification of Implant materials

Types	Materials
Metallic	Co-Cr alloys Stainless steel Precious metals Commercially Pure Titanium (CP-Ti) Titanium alloys
Ceramic and Ceramic-coated	Bio-inert Ceramics Bioactive and biodegradable ceramics
Polymers and composites	Poly (methyl methacrylate), PE, PTEF, PSF
Carbon compounds	

5.1 Metals and alloys

The majority of dental implant systems are made of metals or alloys. Tantalum, titanium, and alloys made of aluminum, vanadium, cobalt, chromium, molybdenum, and nickel are a few examples. The general selection criteria for these materials are their overall strength. Dental implants are not frequently made of precious metals like gold and platinum and their associated casting alloys; instead, restorations are made of these materials [1].

Stainless-steel alloys are well-known implant materials that have been utilised in dental and orthopaedic implants for a long time [1,9]. The ramus blade, ramus frame, stabilizer pins, and various mucosal inserts are made of iron-based alloys. These alloys are primarily composed of nickel, which is prone to corrosion. Furthermore, some people develop allergies to nickel. Stainless-steel alloys, which are frequently utilised with cobalt, titanium, and carbon-based implants, also have a propensity to create a galvanic pair [1].

Cobalt-chromium alloys are utilised in metallurgical processes such as casting or casting and annealing [1, 10]. Subperiosteal frames are frequently constructed using these alloys. The three main elements that make up a cobalt-chromium alloy are cobalt, chromium, and molybdenum. The continuous phase is delivered by cobalt for fundamental characteristics. A passivating element is a chromium. The addition of molybdenum increases the alloy strength and resistance to bulk corrosion. Nickel, manganese, and carbon are also included in these alloys, though in less amounts [1,4]. The bio-corrosiveness of nickel has been found, and carbon must be precisely regulated to retain mechanical characteristics like ductility [11]. The cast-cobalt alloys used for dental surgical implants are typically the least ductile of the alloy systems used for implants, hence bending of finished implants should be avoided. Implants made from these alloys, if properly manufactured, have high biocompatibility characteristics [1,4].

The most common implant material is titanium (Ti), which has good biocompatibility due to the advancement of a stable surface oxide layer. This oxide layer forms so quickly and improves resistance to chemical attack [1,3, 12,13]. There are four categories of commercially pure titanium (cpTi), each with a different level of oxygen concentration. Grade 1 has the least oxygen concentration (0.18 per cent), while Grade 4 has the largest (0.4 per cent). Titanium is a dimorphic metal that occurs as the α-phase (HCP crystal form) at 882.5 °C and transforms into the β-phase above this temperature (BCC) [4,12]. The primary benefits of titanium implants are their excellent resistance to corrosion and an elastic modulus that is close to that of bone [1,6,14]. Titanium has several alloying elements added to it to enhance some of its properties and stable the α- and β-phases at room temperature. The most productive titanium alloys are Ti-6Al-4V, in which vanadium serves as a β-phase stabiliser and aluminium as an α-phase stabiliser [1]. In addition, aluminium also makes the alloy stronger and less dense. The strength of these alloys can also be increased by subjecting them to the heat treatment process [1,3,4,11,15,16].

There have been many surface modifications suggested to improve the osseointegration of titanium-based implants. These include vacuum therapy (plasma treatment and ion implantation), chemical (cleaning and etching), electro-chemical (electro-polishing, and anodization), mechanical (machining, polishing, and blasting), thermal, and laser treatments [6, 17].

5.2 Ceramics

The inertness, superior strength, and physical characteristics of ceramics, such as their low thermal and electrical conductivity, made them ideal for use in surgical implant devices [18]. Ceramics, on the other hand, are less ductile and more brittle in nature. Due to their excellent qualities, researchers have focused mostly on bioactive ceramic materials and the non-reactive family of ceramics among the various types of ceramic implant materials [1,18-20].

Bioactive materials include hydroxyapatite and bioglass. Calcium phosphate-rich hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$) is most frequently utilised as an implant material for enhancing alveolar ridges or filling bone deformities [21].

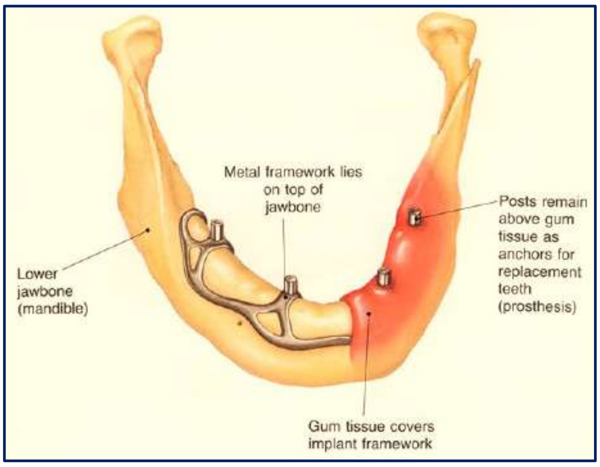

Figure 1. Subperiosteal implant

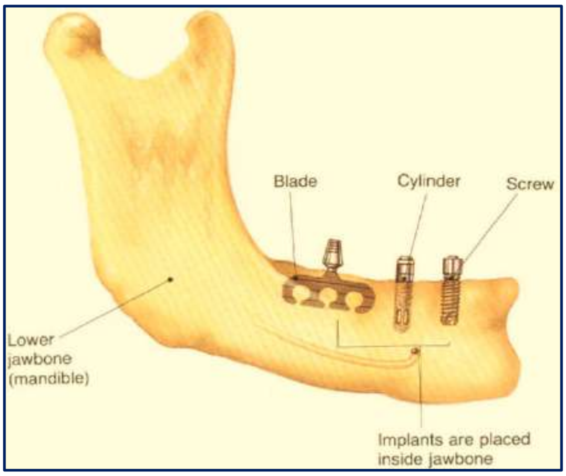

Figure 2. Endosseous implant

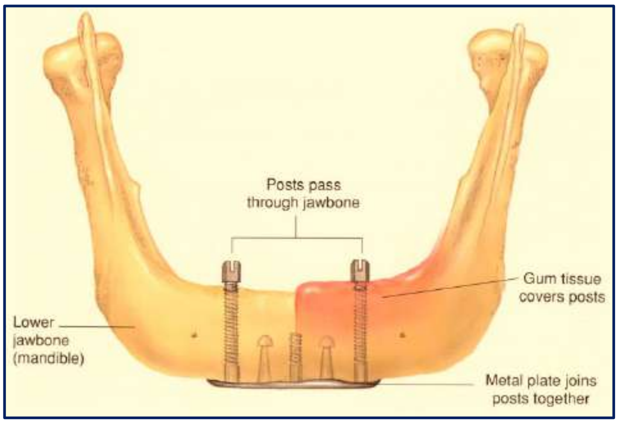

Figure 3. Transosteal implant

These come in a block or granular form that is packed or fitted into the site and acts as a scaffold for the development of new bone. Ceramics have an elastic modulus that is closer to the bone than any other material utilised for load-bearing implants [1,3].

Bioglass is a dense ceramic material made from calcium oxide, sodium oxide, phosphorus pentoxide and silicon dioxide. Bioglass forms a strong bonding layer of approximately 100–200 µm thick is formed with the bone. This layer's thickness is 100 times larger than the hydroxyapatite layers' thickness. The bioglass/bone contact is still intact. If a failure does occur, it can be a cohesive failure that affects the bioglass or the bone [1].

Ceramics from the families of zirconium [22-24], titanium, and aluminium oxides are non-reactive in nature [1]. The root form, endosteal blade, and pin types of dental implants frequently employ these materials. These implants can have a screw- or blade-shaped form. Alumina is one of these and is characterized as a bioactive material since, in contrast to other ceramic materials, it does not promote the creation of bones [1,4].

5.3 Polymers and composites

In 1969, Milton Hodosh developed a dental implant based on polymethyl methacrylate and stated that polymers were biologically acceptable materials. Porous and solid kinds of polymer-based implants have been used for tissue attachment and replacement [1]. The implant materials made of polymers has the following benefits.

- Their ability to modify the compositions and alter the physical characteristics accordingly.
- Easy to manipulate.
- They allow better reproduction.
- In contrast to metals, polymers do not produce electrolytic current or microwaves.
- Polymers exhibit good attachment with fibrous connective tissue.
- Excellent optical properties.

However, polymers exhibit unfavourable immunologic reactions as well as insufficient mechanical characteristics to resist the forces of mastication. Composites with fibre reinforcement have been developed to enhance their resistance to mechanical loads [1,25,26]. Although these materials have a reasonable amount of strength, it is quite challenging to bond the fibres and polymers together. Numerous researchers have also experimented by integrating the polymers with carbon, alumina, and hydroxyapatite fibres or particles.

5.4 Carbon-based implants

Carbon-based biomaterials have been employed for ceramic-like coatings on metallic implants and elicit minimum host reaction. On carbon-coated zirconia, numerous in vitro studies showed superior cell adhesion compared to an uncoated disc. To the contrary of metals, plastics, and other ceramics, these carbonaceous materials do not experience fatigue [27,28]. However, because of their inherent fragility and poor tensile strength, they cannot be used in heavy load-bearing applications [4,16,25,27].

6. Conclusion

Dental implants are emerging as a very acceptable and reliable treatment option for the restoration of human dental and oral structures. Future developments in a new class of binary materials—metal-ceramic formulations with highly modulated surface properties—will be made possible by ongoing research and development in the fields of newer metal alloys and ceramic composites. The advancement of cutting-edge material science technology is still driving to the quest for the ideal biomaterial for dental implants.

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