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Review Article

Dental implant bio materials - From metal to PEEK polymer

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ABSTRACT

Long term clinical success of implants mainly depends upon the implant biomaterial selection. For optimal performance, implant biomaterials should have suitable biocompatibility, mechanical strength and structural biostability in physiologic environment. Every clinician should have a detailed knowledge about the advantages and disadvantages of each bio material. This article reviews the history of evolution of various implant biomaterials and their pros and cons in oral implantology applications.

1. Introduction

The materials that are compatible with the living tissues are known as Biomaterials. A nondrug substance that augment or replace the function of bodily tissue or organ is known as a biomaterial.[1] In Modern dentistry, Dental implant is fabricated through blending of both science and technology based on various concepts like surface engineering, surface chemistry and physics and biomechanics from macro- scale to nanoscale manufacturing technologies.[2]

The physical properties of the materials, their ability for eliciting inflammation or rejection response, induction of tissues, their surface configuration and their potential to corrode in the tissue environment are all important factors; It is mandatory to understand, realize, and utilize the benefits of biotechnology in health care. Surgical implant design and material concepts are optimized with the advancement of biomechanical sciences.[3]

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2. History

2.1. Ancient era (AD 1000)

Evidences for implant usage is found from ancient egyptian and south American civilization.An arabian surgeon Albucasis de condue was credited with a written paper on transplants. It was for replacement of missing teeth.[4] The artificial tooth is carved with dark stone in pre Columbian era.

2.2. Foundational period (1800-1910)

Endosseous oral implantology had its start in this era only.

In 1809 - Tooth root shaped gold was used by Maggiolo.

In 1887 - Harris reported the use of lead coated platinum post fitted teeth made of porcelain.

In 1890 - Zamenski reported the teeth implantation; Rubber, porcelain and gutta-percha were used.

In 1898- R.E payne filled tooth socket with silver capsule.

In the early 1900's - lambotte fabricated of aluminum, red copper, magnesium, silver, brass, gold and soft steel plated with nickel and gold.[4,5]

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2.3. Premodern era (1901-1930)

In 1901- R.E Payne reported a new technique called capsule implantation; He introduced it at the third international dental congress clinics.

In 1903, a tooth made of porcelain was implanted by Scholl in Pennsylvania; It had a root that is made of porcelain and is corrugated.

In 1913, the alveoli was filled with 24 carat gold and iridium by Dr. Edward and greenfield. The ability of tissue to heal and immobility of dental implant in submerged implant[5] concept was also introduced by Greenfield.

2.4. Dawn of the modern era (1935-1978)

In this era, the naturally derived materials are replaced by synthetic polymers, ceramics and metal alloys; They were found to have predictable results and better performance than the natural ones. A vitalium screw was anchored within bone by strock; Immediately a porcelain crown was mounted on it. This implant had survival for 15 years.[5,6]

2.5. Modern Era

From the period of mid 1930's to the present, the modern implant dentistry is delineated; The popularity of dental implants in current period is mainly because of the development and the research work in the biomaterial field; This has laid the foundation of this field.

Table 1: History of implantology - Based on eras[4–6]

Periods	Time
A.D 1000	Ancient era
1000-1800	Medieval era
1801-1910	Foundational era
1911-1935	Premodern period
1936-1978	Pre – Brane mark period (The dawn of modern era)
1978-1998	The Brane mark period (The scientific basis of implantology)

2.6. Requirements of an ideal implant material

The two basic criteria that every dental implant material must meet are:

1. Bio functionality with regard to force transfer.
2. Biocompatibility with living tissue.

Certain basic criteria like ideal mechanical, chemical, physical and biological properties have to be fulfilled by the implant material; Few accepted guidelines for dental implants according to ADA specifications are:

1. Assessment of physical properties to measure the material strength.
2. Freedom from defects.
3. Evaluation of biocompatibility and safety with tissue interference & cytotoxicity testing characteristics.
4. Ease of fabrication.
5. Sterilization potential without causing any degradation of material.
6. Assessment of efficacy: It should be done with at least two independent longitudinal prospective clinical studies.

3. Classification

3.1. Based on composition

1. Metal and Metal alloys
   - (a) Titanium
   - (b) Titanium alloys (Ti6Al4V)
   - (c) Precious metals (Gold, Platinum, Palladium)
   - (d) Cobalt, Chromium, Molybdenum alloy (Vitalium)
   - (e) Austenitic steel or Surgical steel (Iron, Chromium, Nickel alloy)
2. Ceramics and carbon
   - (a) Aluminium oxide Alumina Sapphire
   - (b) Zirconium oxide (zirconia)
   - (c) Glass ceramics
   - (d) Titanium oxide (titania)
   - (e) Calcium phosphate ceramics (CPC)
     - i. Hydroxyapatite (HA)
     - ii. Tricalcium phosphate (TCP)
   - (f) Vitreous carbon (C), Carbon-silicon(C-Si)
3. Polymers
   - (a) Poly methyl metha acrylate (PMMA)
   - (b) Poly ethylene terapthylate(Dacron)
   - (c) Poly tetra fluoro ethylene (PTFE)
   - (d) Poly sulphone
   - (e) Ultrahigh molecular weight poly ethylene (UHMWPE)
   - (f) Dimethyl polysiloxane(Silicone rubber)
4. Composites
   (synthetic biomaterial and polymer combination)
   - (a) Carbon – PTFE
   - (b) Carbon- PMMA
   - (c) Alumina- PTFE

3.2. Biological classification – According to tissue response

According to property of bio compatibility , biomaterials are broadly classified into three major categories: bioactive, bioresorbable and bioinert.

Table 2: ndosseous dental implant materia**ls**

Implant Material	Common Name or Abbreviation
I. Metals	
Titanium	CpTi
	Ti-6A1-4V extra low interstitial (ELI)
	Ti-6A1-4V Ti-5Al-2.5Fe
	Ti-6Al-7Nb
Titanium Alloys	Ti-29Nb-13Ta-4.6Zr
	Ti-15 Zr-4Nb-2Ta-0.2Pd
	Roxolid (83%–87%Ti-13%–17%Zr)
Stainless Steel	SS, 316 LSS
Cobalt Chromium	Vitallium,
Tantalum Ta	Co-Cr-Mo
Gold Alloys Au	
II. Ceramics	
Alumina	Al2O3, polycrystalline alumina or single-crystal sapphire
Hydroxyapatite	HA, Ca10(PO4)10, (OH)2
Beta-Tricalcium phosphate	β-TCP, Ca3(PO4)2
Carbon	C vitreous low-temperature isotropic (LTI)
	Ultralow- temperature isotropic (ULTI)
Carbon-Silicon	C-Si
Bioglass	SiO2/CaO/Na2O/P2O5
Zirconia	ZrO2
Zirconia-toughened alumina	ZTA
III. Polymers	
Polymethylmethacrylate	PMMA
Polytetrafluoroethylene	PTFE
Polyethylene	PE
Polysulfone	PSF
Polyurethane	PU
Polyether ether ketone	PEEK

Based on: Berner et al., 2009[7]; Sagomonyants et al., 2007[8];
Based on: Berner et al., 2009; Sagomonyants et al., 2007
Craig, 1993; Lemons, 1990; Williams, 1981.

1. Bioactive- These materials react with hard and soft tissues when they are placed inside the oral cavity. Glass ceramic, bio glass and synthetic hydroxyapatite are few examples.
2. Bioresorbable – When these materials start resorbing bone replaces them. Examples are tricalcium phosphate, calcium carbonate, gypsum, polylactic–polyglycolic acid copolymers and calcium oxide.
3. Bioinert – These materials have less interaction with the surrounding tissue; It leads to osteogenesis. Few examples are alumina, stainless steel, zirconium and titanium and ultra-high-molecular-weight polyethylene.

The term "osteoconductive" refers to bioinert and bioactive materials; These materials can act as "scaffolds" for bone deposition on its surface. Bioinert materials allow close approximation of bone. Their surface leading to contact osteogenesis. These materials allow the formation of new bone on their surface and ion exchange with the tissues leads to the formation of a chemical bonding along the interface bonding osteogenesis. Biotolerant are those that are not necessarily rejected when implanted into living tissue. They are human bone morphogenetic protein-2 (rh BMP-2), which induces bone formation de novo Bioinert materials allow close approximation of bone on their surface leading to contact osteogenesis. These materials allow the formation of new bone on their surface and ion exchange with the tissues leads to the formation of a chemical Bioinert materials allow close approximation of bone on their surface leading to contact osteogenesis. These materials allow the formation of new bone on their surface and ion exchange with the tissues leads to the formation of a chemicalnert materials allow close approximation of bone on their surface leading to contact osteogenesis. These materials allow the formation of new bone on their surface and ion exchange with the tissues leads to the formation of a chemical bonding along the interface bonding osteogenesis.

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Table 3: Based on the type of material used and the biologic response they elicit when implanted:

Biodynamic activity	**Chemical composition**		
	Metals	Ceramics	Polymers
Biotolerant	Gold		Polyethylene
	Co-Cr alloys		Polyamide
	Stainless steel		Polymethyl-methacrylate
	Niobium		Polyurethane
	Tantalum		Polytetrafl-uroethylene
Bio inert	Commercially pure titanium	Al oxide	
		Zirconium oxide	
Bioactive	Titanium alloy (Ti-6AL-4U)	Hydroxyapatite	
		Tricalcium phosphate	
		Bio glass	
		Carbon-silicon	

Table 4: Coating of dental implant ceramic materials

Material	**Chemical Composition**
Hydroxyl apatite(HA)	Ca10(PO4)6(OH)2
Tricalcium phosphate (TCP)	α, β,Ca3(PO4)2
Tetra calcium phosphate	Ca4P2O9
Fluorapatite (FA)	Ca10(PO4)6F2
Calcium pyrophosphate	Ca4P2O7
	CaHPO4
	CaHPO4·2H2O
Bio glasses	SiO2-CaO-Na2O-P205-MgO
Aluminium oxide	Al2O3
Zirconium oxide	ZrO2

According to Lace field, 1998[9]

4. Discussion

In patients with edentulism the QOL (Quality Of Life) is improved by rehabilitation with oral implants.[10] Brane mark, introduced pure titanium in 1960s and it remained the material of choice for oral end osseous implants.[11] Different materials such as metals, alloys, glasses, carbon, ceramics and polymer-based materials have been used as oral implants from ancient era to modern era of dental implant history.[12–15]

These different oral implant materials interact with the human body at different degrees.[15,16] The mechanical, chemical and biological properties of a bio material together with the ability to Osseo integrate are the ideal requirements of an oral implant bio material.

Although hypersensitivity is one of the most common problem reported with titanium implant,[17–21] they have excellent mechanical properties like good fracture strength; The second common problem reported with these titanium implant is mainly due to the difference in the elastic moduli gradient of surrounding bone and the titanium implant. Stress concentrations occur at the bone-implant interface during load transfer.[22,23] The result is bone loss around the implant.[24,25]

Titanium implants may cause aesthetic problems due to their lack of light transmission.[26] In cases of thin mucosal biotype and/or mucosal regression, the peri-implant soft tissue around titanium implants may appear dark. If the smile line is high, more aesthetic problems occur.[27,28] Patient demand for metal-free oral biomaterials is also increasing.

All implant biomaterials have their own advantages and disadvantages; PEEK is considered as a good biomaterial for dental implants due to its good properties such as low plaque affinity, high biocompatibility and good aesthetics.[29] The main advantage of PEEK as an implant material is that its Young's modulus is close to that of human bones, thus increasing stress and deformation, reducing stress resistance and bone resorption. Unfilled PEEK has an elastic modulus of 3-4GPa. The addition of additional materials such as carbon fibers increases PEEK's modulus of elasticity to 18Gpa compared to bone (14Gpa). Thus, PEEK can substitute titanium.[30,31]

PEEK is an alternative to ceramic in terms of mechanical properties. Although unmodified PEEK is considered a bioinert material, there is no conclusive evidence of osteoconductive effects. Therefore, the survival of unmodified Peek implant is questionable. Inadequate osteo conductivity and bioactivity of dental implants can lead to severe implantitis and implant rejection. These are some of the current strategies to improve PEEK bioactivity.[32] PEEK can be viable alternative to titanium abutments.[33] How ever, because of its lower fracture resistance PEEK is not used as a definitive abutment material.[34]

Compared to all thermoplastic composites, PEEK biomaterials are with excellent shock absorption and fracture resistance. Further improvements in material properties and surface modifications allow for wide applications in the field of dental implants. A limited number of studies on PEEK implants have been published and long-term follow-up studies are needed due to the recent use of the material in dentistry.

5. Conclusion

There is an ongoing research process for the "perfect" dental implant biomaterial. In future, the dental implant biomaterial research will be focused on the cutting-edge interface of material science.

With continued research and development in the field of new metal and polymer materials, the future will see many innovations in new metal-polymer binary materials formulations with excellent properties.

Biomaterials can represent a combination of performance, strength, predictability and integrity. Three-dimensional (3-D) printing/molding techniques using elements of nanotechnology will advance these innovations.

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None.

7. Conflict of Interest

None.

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