

# A Review on Recent Applications of Biomaterials

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**Abstract:** *The study of biomaterials is called biomaterial science. Biomaterial science encompasses the fields of medicine, biology, chemistry, tissue engineering, biochemistry, and pharmaceuticals and material science. Biomaterials in the form of implants and medical devices are widely used to replace and/or restore the function of degenerated tissues or organs and this improve the quality of life of patients. Biomaterials can totally/partially replace one or more parts of the body. This paper describes about classification of different biomaterials which are used in medical industries. The most common classes of materials used as biomedical materials are metal, polymers, ceramics and composite. Conventional materials such as metals, ceramics and synthetic polymers are usually bioinert and support the structural defects. Before using biomaterials, it should in mind that, which categories they are belongs and main focuses are on biocompatibility, bioinert, bioactive, adequate mechanical and physical properties etc. But recently introduced biomaterials are designed to provide biological functions as much as possible by mimicking tissue structures. This review is mainly focused on recent and relevant applications of biomaterials and should be of value to researchers who are interested in the state of the art of biomaterial evaluation and selection of biomaterials.*

**Keywords:** biocompatibility, conventional materials, biological functions.

## 1. Introduction

Over the centuries, advancements in synthetic materials, surgical techniques and sterilization methods have permitted the use of biomaterials in many ways. Medical practice today utilizes a large number of devices and implants. Biomaterials in the form of implants (ligaments, vascular grafts, heart valves, intraocular lenses, dental implants, etc.) and medical devices (pacemakers, biosensors, artificial hearts, etc.) are widely used to replace and/or restore the function of traumatized or degenerated tissues or organs, and thus improve the quality of life of the patients. In the early days all kinds of natural materials such as wood, glue and rubber, and tissues from living forms, and manufactured materials such as iron, gold, zinc and glass were used as biomaterials. Under certain conditions (characteristics of the host tissues and surgical procedure) some materials were tolerated by the body, whereas the same materials were rejected in another situation. Over the last 30 years considerable progress has been made in understanding the interactions between the tissues and the materials. In general, materials used in medicine which are classified Class I materials are those that do not directly contact bodily tissues; Class II materials are those that contact intermittently or instantly to tissues; and Class III materials are those that are constantly contacting tissues as implants. These days, it is the Class III materials which are called biomaterials or biomedical materials. These Class III materials are divided into 3 categories according to their biological interactions with surrounding tissues. Bioinert materials do not produce any immunological host reactions but retain their structure in the body after implantation. Bioactive materials demonstrate biological functions mimicking the tissue, and finally, biodegradable

materials are dissolved in body and replaced by regenerated natural tissues. The term 'biomaterial' has been difficult to formulate, more widely accepted working definitions include: "A biomaterial is any material, natural or man-made, that comprises whole or part of a living structure or biomedical device which performs, augments, or replaces a natural function". A wide range of materials encompassing all the classical materials such as Metals (gold, tantalum, Ti<sub>6</sub>Al<sub>4</sub>V, 316L stainless steel, Co-Cr Alloys, titanium alloys), Ceramics (alumina, zirconia, carbon, titania, bioglass, hydroxyapatite(HA)), Composite (Silica/SR, CF/UHMWPE, CF/PTFE, HA/PE, CF/epoxy, CF/PEEK, CF/C, Al<sub>2</sub>O<sub>3</sub>/PTFE), Polymers (Ultra high molecular weight polyethylene(UHMWPE), Polyurethane(PE), Polyurethane (PU), Polytetrafluoroethylene (PTFE), Polyacetal (PA), Polymethylmethacrylate (PMMA), Polyethylene Terephthalate (PET), Silicone Rubber (SR), Polyetheretherketone (PEEK), Poly(lactic acid) (PLA), Polysulfone (PS)) have been investigated as biomaterials. Biomaterials must be nontoxic, non-carcinogenic, chemically inert, stable, and mechanically strong enough to withstand the repeated forces of a lifetime. Newer biomaterials even incorporate living cells in order to provide a true biological and mechanical match for the living tissue.

## 2. Biocompatibility

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**Challenge:** biocompatibility with optical term and combining ion. The primary requirement to use an implantable material in medicine is that the material should be biologically adaptable to the bodily system. This biological adaptation consists of biological stability and compatibility to the tissue. Generally, biostability is defined, in relation to host immune reactions, as any biomaterial not having pyrogenic, inflammatory, cytotoxic, antigenic, and oncogenic characteristics after implantation, while biocompatibility is defined as the need for any biomaterial to be mechanically, volumetrically and biochemically harmonized with the nearby tissue.

Anatomically, the size and shape of an implanted material should be accurately suitable to the lesion that is to be reconstructed, and the mechanical properties such as Young's modulus also have to be similar to those of the lost tissue to avoid mechanical deterioration or fatigue. The continuously accumulated physical stress in the implanted material is not only directly related to its durability, but it also induces tissue resorption or, in reverse, hypertrophy. Every biomaterial has the potential to induce biological dysfunctions in the surrounding tissues after implantation. The interface between the material and tissue is the key area where the biological disturbance is initiated. To restore a tissue defect caused by an artificial material, the *in vitro* and *in vivo* investigations of the released substance from the material surface are indispensable in determining the biochemical characteristics of the material. The implanted material should not inhibit the biological function of the host with having an acceptable biocompatibility. The operational definition of biocompatible is "The patient is alive so it must be biocompatible".

### 3. Literature Survey of Implantable Materials

The science of biomedical materials involves a study of the composition and properties of materials and the way in which they interact with the environment in which they are placed. The most common classes of materials used as biomedical materials are metals, polymers, ceramics, and composite. These four classes are used singly and in combination to form most of the implantation devices available today.

#### 3.1 Metals and Alloys

Biomaterials for skeletal systems have mainly been made of metals. Metals have been used almost exclusively for load-bearing implants, such as hip and knee prostheses and fracture fixation wires, pins, screws, and plates. Although pure metals are sometimes used, alloys frequently provide improvement in material properties, such as strength and

corrosion resistance. Three material groups dominate biomedical metals: Stainless steel, cobalt-chromium-molybdenum alloy, titanium and titanium alloys. The main considerations in selecting metals and alloys for biomedical applications are their excellent electrical and thermal conductivity, biocompatibility, appropriate mechanical properties, corrosion resistance, and reasonable cost. It is very important to know the physical and chemical properties of the different metallic materials used in any surgery as well as their interaction with the host tissue of the human body.

#### 3.1.1 Austenitic Stainless Steel

(ASTMF138/139, F1314, F1586, F2229)

The stainless steel compositions (all fcc austenitic stainless steels) recommended for implant use. 316L austenitic stainless steel (ASTMF138/139), despite its great susceptibility to crevice corrosion compared to other common metallic biomaterials has over decades of use proved acceptable and devices. Stainless steel corrosion resistance is dependent on the formation of a thin Cr, Mo-containing passive surface oxide layer, the Mo imparting stability in a  $Cl^-$  containing environment. It forms a single phase (fcc austenite phase) from its forging temperature ( $\sim 1050^\circ C$ ) to room temperature and achieves its reasonable strength and fatigue resistance through strain hardening and solid solution strengthening mechanisms and a fine grain size. High nitrogen content in some stainless steels (ASTMF1314, ASTM F1586, ASTM F2229) results in higher strength (due to greater solid solution strengthening) as well as improved crevice and pitting corrosion resistance. Austenitic stainless steels are also used for fabricating vascular stents as well as electrodes, conducting lead wires and pulse generator housings of cardiac pacing systems (304, 316, 316L alloys).

#### 3.1.2 Co-based alloys

Co-based alloy implants can be formed by casting or forging, the latter using bar or rods stock made by conventional forming of cast billets (rolling, extrusion), or by hot isostatic pressing of Co alloy powders. Additionally, novel methods for near net-shape formation of parts from metal powders (metal injection molding or MIM) are currently being explored. CoCrMo implant alloys all contain Cr ( $\sim 26-30wt\%$ ), Mo ( $5-7wt\%$ ), Some Ni ( $1wt\%$  maximum in order to minimize concerns related to possible Ni sensitivity), other residual trace elements (Mn, Fe, Si, N), and C (either low-C  $\sim 0.05wt\%$  or high-C  $\sim 0.25wt\%$ ). To achieve secure implant-to-bone fixation without the use of a acrylic bone cement, cast CoCrMo implant surfaces can be modified by either sintering CoCrMo powders to the bone-interfacing surfaces or plasma spray coating the surfaces. For the sintered coatings, typically  $250-350\mu m$  size powders ( $-45/+60$  mesh) are used to form porous coatings of approximately 50–70% density (i.e., vol.% porosity  $\sim 30-50\%$ ). Secure particle-to-particle and particle-to-substrate core bonding is achieved by sintering CoCrMo alloy powder at around  $1300^\circ C$  for a period of 1 hour. This high temperature interdiffusion significantly alters the microstructure and mechanical

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properties of both cast and wrought CoCrMo alloys. Further, the more homogenous compositions of the wrought alloy substrates reduces significantly the amount of  $M_{23}C_6$ - $\gamma$ -phase eutectic formation. As a result, higher mechanical properties of wrought high-CrCo alloy porous-coated samples can be achieved. Other Co-based alloys that are used in implant applications include Elgiloy (ASTMF-1058) and the W-containing alloys (ASTMF-563). Elgiloy is renowned for its high spring back qualities when highly cold-worked, a property that makes it attractive for fabrication of neuro surgical and vascular implants (neural aneurysm and microvascular clamps) as well as conducting leads for pacemakers. The W-containing CoCrNi alloy (ASTMF-563) has been used for making fracture fixation implants.

### 3.1.3 Titanium Based Alloys

Titanium and its alloys have been used increasingly for fabrication of orthopedic implants. They are also used virtually exclusively for forming endosseous dental implants, another mechanically-loaded application requiring implants with good fatigue resistance characteristics. The increasing use of Ti-based metals, in addition to their good fatigue resistance is attributed to their excellent in vivo corrosion resistance, a feature related to the stable passive oxide layer ( $TiO_2$ ) that rapidly forms, their lower elastic moduli compared to other metallic bio materials and their strong osseointegration tendency (i.e., development of close bone-to-implant apposition after short implant at ion periods). This latter characteristic represents an important advantage for permanent bone interfacing implants. This is believed to be due to  $OH^-$  ion incorporation with in the passive  $TiO_2$  layer and reaction of the resulting hydroxylated surface zone with bone mineral phase constituents calcium ion and phosphate ions. Strain hardening during mechanical forming of parts, its fine grain size, and interstitial solid solution strengtheners such as oxygen and nitrogen are responsible for strengthening CP Ti. Alloying of Ti is used to form a two-phase ( $\alpha+\beta$ ) alloy of higher strength (yield, ultimate and fatigue) than CP Ti while maintaining excellent corrosion resistance and osseointegration tendency, again because of the  $TiO_2/OH$  surface film that rapidly forms. The ( $\alpha+\beta$ ) Ti alloy with the longest history of use for major load-bearing applications is Ti 6Al4V alloy with Ti6Al7Nb and Ti5Al2.5Fe being more recent alternatives that are similarly processed giving similar properties. All three alloys behave equally well in clinical use. The excellent corrosion resistance of Ti6Al4V makes it an attractive choice for forming high surface area, porous-coated or other surface-textured orthopedic implants either by sintering Ti or Ti alloy powders or fibers to the surface of machined substrates or by plasma spray deposition of Ti.

### 3.1.4 Ni-Ti Alloys (Nitinol)

The equi atomic Ni-Ti alloy (Nitinol) is used currently in orthopedic, dental and cardiovascular applications. The shape-memory effect that the alloy displays as well as its reported good corrosion resistance (the result of a  $TiO_2$  passive surface layer) and its pseudo elastic property has attracted considerable interest in the biomaterials field in recent years. The shape memory effect is due to the thermo

elastic martensitic transformation that occurs with the Ni-Ti shape memory alloys.

### 3.1.5 Recent developments in metals for biomedical devices

Along with the advances in biomedical technology and tissue engineering, biomaterials are desired to exhibit low elastic modulus, shape memory effect or super elasticity, wear resistance, super plasticity and workability. In addition, they are required to eliminate all possibility of toxic effects from leaching, wear and corrosion. One of the concerns is avoiding the use of Ni in fabricating metal alloys. This demand leads to the development of new generation of metallic biomaterials and their novel processing.

### 3.1.6 New generation of metallic biomaterials

Stainless steels for metal implants have been further developed to be Ni-free. Replacing Ni with other alloying elements while maintaining the stability of austenitic phase, corrosion resistance, magnetism and workability, has led to the use of nitrogen creating FeCrN, FeCrMoN and FeCrMnMoN systems. In CoCr alloys system, maximizing C content to its upper limit and addition of Zr and N with optimal precipitation hardening permit the formation of fine and distributed carbides and which in turn improves the wear resistance of cast CoCr alloy. For wrought CoCr alloys, addition of N and suppression of carbides and intermetallics results into the desired better workability.

## 3.2 Ceramics

Ceramics are defined as materials with regularly-aligned mineral crystal molecules. Ceramics include a variety of biomaterials, such as calcium and carbon phosphates and alumina. Both surgeons and researchers have shown great interest in them. In this group hydroxyapatite (HAp) has a dominant place, being used for oral and maxillofacial surgery as bone substitute and as coating for metal and carbon implants. HAp is found in different parts of the body as a constituent of various types of calcified tissues. Calcified tissues include tooth enamel (95 % HAp), dentin (75 % HAp) and cement (35 % HAp); the bone contains an organic part and an inorganic part (70 %) which includes HAp and tri calcium phosphate. The mineral phase of the bone is mainly made up of calcium phosphate micro-crystals, among them hydroxyapatite is the most important, its chemical formula reads  $Ca_{10}(PO_4)_6(OH)_2$ . Ceramics are polycrystalline materials. The main characteristics of ceramic materials are hardness and brittleness, great strength and stiffness, resistance to corrosion and wear, and low density. They work mainly on compression forces; on tension forces, their behavior is poor. Ceramics are typically electrical and thermal insulators. Ceramics are used in several different fields such as dentistry, orthopedics, and as medical sensors. Overall, however, these biomaterials have been used less extensively than either metals or polymers. Ceramics typically fail with little, if any, plastic deformation, and they are sensitive to the presence of cracks or other defects. Ceramics have become a diverse class of biomaterials presently including three basic types: bioinert, bioactive, biodegradable ceramics. Alumina ( $Al_2O_3$ ), Zirconia ( $ZrO_2$ )



and Pyrolytic carbon are termed bioinert. Bioglass and glass ceramics are bioactive. Calcium phosphate ceramics are categorized as bioresorbable. *Bioinert* refers to a material that retains its structure in the body after implantation and does not induce any immunologic host reactions.

### 3.2.1 Alumina (Al<sub>2</sub>O<sub>3</sub>)

High density high purity (>99.5%) alumina (Al<sub>2</sub>O<sub>3</sub>) was the first ceramic widely used clinically. It is used in load-bearing hip prostheses and dental implants, because of its combination of excellent corrosion resistance, good biocompatibility, and high wear resistance, and high strength. The reasons for the excellent wear and friction behavior of (Al<sub>2</sub>O<sub>3</sub>) are associated with the surface energy and surface smoothness of this ceramic. The cytotoxicity of single crystal alumina ceramics was studied in L cell line culture. They displayed the same colony formation and survival rates as the controls showed that they have no cytotoxicity and if implanted in bone marrow they would not be toxic to circumferential tissue.

### 3.2.2 Zirconia (ZrO<sub>2</sub>)

Zirconia is a biomaterial that has a bright future because of its high mechanical strength and fracture toughness. Zirconia ceramics have several advantages over other ceramic materials due to the transformation toughening mechanisms operating in their microstructure that can be manifested in components made out of them. The research on the use of zirconia ceramics as biomaterials commenced about twenty years ago and now zirconia is in clinical use in total hip replacement (THR) but developments are in progress for application in other medical devices. Today's main application of zirconia ceramics is in THR ball heads.

### 3.2.3 Pyrolytic Carbon

Carbon is a versatile element and exists in a variety of forms. Good compatibility of carbonaceous materials with bone and other tissue and the similarity of the mechanical properties of carbon to those of bone indicate that carbon is an exciting candidate for orthopedic implants. Unlike metals, polymers and other ceramics, these carbonaceous materials do not suffer from fatigue. However, their intrinsic brittleness and low tensile strength limits their use in major load bearing applications. The mechanical bonding between the carbon fiber reinforced carbon and host tissue was investigated. The bonding developed three months after intrabone implantation and is accompanied by a decrease of the implant strength. *Bioactive* refers to materials that form direct chemical bonds with bone or even with soft tissue of a living organism.

### 3.2.4 Bioglass & Glass Ceramic

A common characteristic of such bioactive materials is a modification of the surface that occurs upon implantation. Bonding to bone was first demonstrated for a range of bioactive glasses, which contained specific amounts of SiO<sub>2</sub>, CaO, and P<sub>2</sub>O<sub>5</sub>. This material has been widely used for filling bone defects. The porosity of bioglass is beneficial for resorption and bioactivity. The interface reaction was interpreted as a chemical process, which includes a slight solubility of the glass ceramic and a solid-state reaction

between the stable apatite crystals in the glass ceramic and the bone. *Biodegradable* refers to materials that degrade (by hydrolytic breakdown) in the body while they are being replaced by regenerating natural tissue; the chemical by-products of the degrading materials are absorbed and released via metabolic processes of the body.

### 3.2.5 Calcium phosphate ceramics

Different phases of calcium phosphate ceramics are used depending upon whether a resorbable or bioactive material is desired. Calcium phosphate (CaP) biomaterials are available in various physical forms. One of their main characteristics is their porosity. The ideal pore size for bioceramic is similar to that of spongy bone. The prime requirement for calcium phosphate materials to be bioactive and bond to living bone is the formation of a bone like apatite layer on their surface.

### 3.2.6 Bioceramics

In general, ceramics show high resistance to corrosion and low electrical and thermal conductivities. These characteristics make them very suitable for implants. A significant influence in bone tissue regeneration is given to phosphate salts because their physical, chemical and structural properties are very similar to those of bone tissue. They promote the formation of new bone tissue, particularly when the atomic ratio for these salts is between 1.5 and 1.7. Success of calcium phosphates in vivo implants depends on several factors, but very ones are the Ca/P atomic ratio, the porosity and the crystalline structure.

## 3.3 Polymeric Biomaterials

Almost all bodily organs except the skeletal system consist of soft tissues, and provide physiological and biochemical functions. But there is no artificial biomaterial that has the same biological functions of the natural tissues, therefore, the search for materials which can provide a favorable environment for regenerating tissue or mimicking tissue structure has been undertaken with a focus on the development of synthetic polymers. The development of polymeric biomaterials can be considered as an evolutionary process. In the fabrication of synthetic polymers, the chemical and mechanical properties of the base polymer can be easily modified to adjust to the characteristics which the material should possess. Homopolymers are composed of a single type of monomer, and there are many homopolymeric biomaterials. Copolymers consist of different monomers and this is very useful in producing a polymer that has concentrated advantages from each monomer.

### 3.3.1 Poly (methyl methacrylate), PMMA

It can be prepared under ambient conditions so that it can be manipulated in the operating theater or dental clinic, explaining its use in dentures and bone cement. The relative success of many joint prostheses is dependent on the performance of the PMMA cement, which is prepared intraoperatively by mixing powdered polymer with monomeric methylmethacrylate, which forms dough that can be placed in the bone, where it then sets.

### 3.3.2 Silicone Rubbers

Both heat-vulcanizing and room temperature vulcanizing silicones are in use today and both exhibit advantages and disadvantages. Room temperature vulcanizing silicones are supplied as single-paste systems. Heat-vulcanizing silicone is supplied as a semi-solid material that requires milling, packing under pressure.

### 3.3.3 Ultra High Molecular Weight Polyethylene (UHMWPE)

Much research is progressing in examining the wear properties of UHMWPE. The coefficient of friction between polyethylene and cobalt-chromium alloy has been reported to be between 0.03 and 0.16, with excellent wear rates. UHMWPE is used as the bearing surface in total joint arthroplasty, it has 90% success rates at 15 years with metal on polyethylene. Submicron particles found in periprosthetic tissues when polyethylene wear present. The mechanical properties of polymers depend on several factors, including the composition and structure of the macromolecular chains and their molecular weight. Examples of current applications include vascular grafts, heart valves, artificial hearts, breast implants, contact lenses, intraocular lenses, components of extracorporeal oxygenators, dialyzers and plasmapheresis units, coatings for pharmaceutical tablets and capsules, sutures, adhesives, and blood substitutes, kidney, liver, pancreas, bladder, bone cement, catheters, external and internal ear repairs, cardiac assist devices, implantable pumps, joint replacements, pacemaker, encapsulations, soft-tissue replacement, artificial blood vessels, artificial skin, Dentistry, Drug delivery and targeting into sites of inflammation or tumors, Bags for the transport of blood plasma.

### 3.3.4 Biodegradable Polymeric Biomaterials

Surgical implants made from biodegradable biomaterials could be used as a temporary scaffold for tissue regeneration. This approach toward the reconstruction of injured, diseased, or aged tissues is one of the most promising fields in the 21st century. While aromatic polyesters are almost totally resistant to microbial attack, most aliphatic polyesters are biodegradable due to their potentially hydrolyzable ester bonds. Naturally produced: Polyhydroxyalkanoates, Synthetic: Polybutylene succinate, polycaprolactone, Polyanhydrides, Polyvinyl alcohol, Most of the starch derivatives, Cellulose esters like cellulose acetate and nitrocellulose and their derivatives (celluloid) are recently used.

### 3.4 Composite Biomaterials

The term "composite" is usually reserved for those materials in which the distinct phases are separated on a scale larger than the atomic, and in which properties such as the elastic modulus are significantly altered in comparison with those of a homogeneous material. Accordingly, reinforced plastics such as fiberglass as well as natural materials such as bone are viewed as composite materials. Natural composites include bone, wood, dentin, cartilage, and skin. Natural foams include lung, cancellous bone, and wood. Natural composites often exhibit hierarchical structures in which particulate, porous, and fibrous structural features are seen on

different micro-scales. Bone itself achieves most of its mechanical properties as a natural composite material composed of calcium phosphate ceramics in a highly organized collagen matrix. Composite biomaterials are made with a filler (reinforcement) addition to a matrix material in order to obtain properties that improve every one of the components. The first composite to come into general use, initially made by an orthopedic surgeon, was the plaster of Paris bandage. A composite for internal prosthetic applications is based on the addition of chopped carbon fiber to improve the mechanical properties of polyethylene components. Only carbon fiber is being studied for orthopedic applications. Implants in this category will be available in the future, perhaps even containing bone inductive proteins.

## 4. Conclusions

Before using biomaterials, it should in mind that, which categories they are belongs so that there is no negative effect in the body. Main focuses are on biocompatibility, bioinert, bioactive or surface reactive, biodegradable, sterilizability, adequate mechanical and physical properties, manufacturability, low weight, reasonable cost etc. Medical research continues to explore new scientific frontiers for diagnosing, treating, curing, and preventing diseases at the molecular/genetic level. This review should be of value to researchers who are interested in the state of the art of biomaterial evaluation and selection of biomaterials.

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