Nano-Biomaterials: A Beginner's Guide

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ABSTRACT

When a medical device is meant to interact with biological systems, the term "biomaterial" should be used. Nano-sized biomaterial particles (1–100 nm) have several uses in tissue engineering, cancer treatment, drug and gene delivery, medical imaging, and more in the biomedical sector. An inert substance, such as silica monolayers, protects the nanoparticle core of a nano-biomaterial. Polymers, metals and alloys, ceramics and composites, as well as other biomaterials, are examined in this article initially. Collagen, a natural biomaterial, is used extensively in medical implants. An implanted synthetic material's effect on a live creature has also been explored. Some uses have been briefly mentioned because of the introductory nature of this article and because the medical applications of biomaterials are thoroughly discussed by top researchers in subsequent chapters of the same book.

Keywords

Biomaterials, Nano-biomaterials, Polymers, and Metals & Alloys, Collagen (HA), Hydroxyapatite (HA), Tissue engineering

1. INTRODUCTION

In the context of biomedical applications, the term "biomaterial" is often used to refer to materials that are not biological, such as synthetic polymers.[1] One definition of a biomaterial is a material that may be used indefinitely to treat, strengthen or replace any part of the body or function[2]. "A synthetic substance used to replace part of a live system or function in close contact with living tissue"[3] is another definition for biomaterial. Nano-biomaterials, such as nano-muscle fibres, nano-apatite grains, nano-membrane, and so on, may be seen as a composite of biological tissue.[4] Tissue engineering, biosensors, bioimaging, drug delivery and gene delivery, wound healing, medical implants and diagnostic systems such as protein- and DNA microarrays are just some of the many biomedical applications for nano-biomaterials that have long been the subject of active study. Researchers have been able to create nanoparticles, nanofibers, nanocoatings, and nanocomposites for biomedical purposes due to the fast rise of nanotechnology. Biological features of a nano-functionalized surface have been postulated by Liu et al.[5]. Thus, nanostructured surfaces may enhance the therapeutic uses of biomaterials.

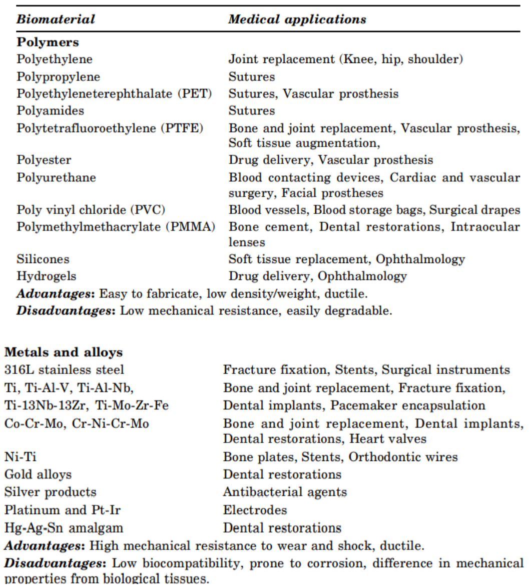
2. REQUIREMENTSFOR BIOMATERIALS

Because a biomaterial is intended to be utilised in close proximity to live tissues, it must be free of any toxic effects on the host tissues and organs and non-toxic to the body[6]. Therefore, an ideal biomaterial must have a chemical composition that is biocompatible in order to prevent tissue reactions, be resistant to biological degradation in the case of polymers and corrosion resistance in the case of metals, have high wear resistance, acceptable physical and mechanical properties to sustain cyclic loading and aesthetic appeal in some cases.

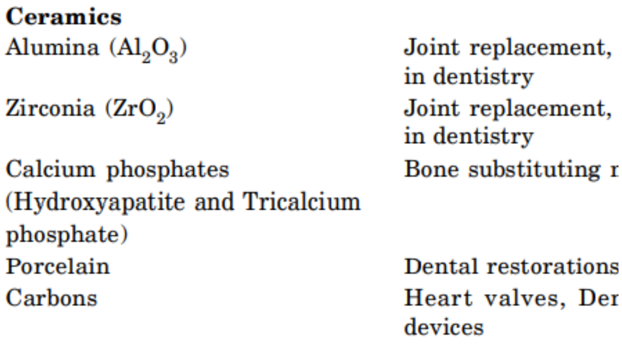
3. CONVENTIONAL BIOMATERIALS

The biomaterials that are presently being employed in clinical applications are briefly discussed in this section. Polymers, metals, ceramics, and composites are the four main categories of biomaterials used in medicine. Conventional biomaterials are included in Table 1 along with their pros and drawbacks, as well as their medicinal uses. Figure 1 illustrates how these biomaterials may be used in the human body. There are many different types of polymers, and each one has a lengthy chain of repeating units. A single polymer molecule may contain tens of thousands, or even hundreds of thousands, of units. Carbon is the primary building block of most polymers, making them organic.

Table 1: Conventional biomaterials with their medical applications and characteristics[8,9]

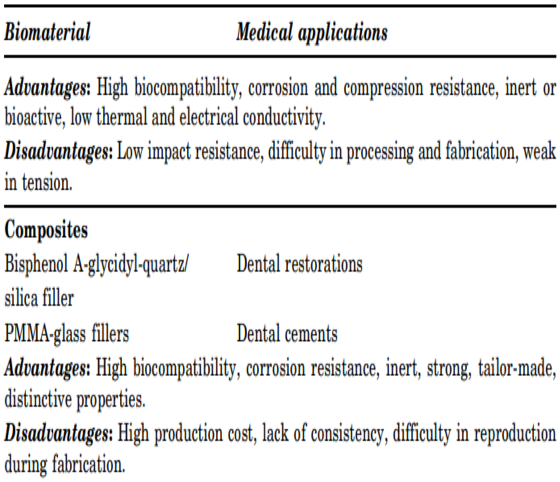


Biomaterial	*Medical applications*
Polymers	
Polyethylene	Joint replacement (Knee, hip, shoulder)
Polypropylene	Sutures
Polyethyleneterephthalate (PET)	Sutures, Vascular prosthesis
Polyamides	Sutures
Polytetrafluoroethylene (PTFE)	Bone and joint replacement, Vascular prosthesis, Soft tissue augmentation,
Polyester	Drug delivery, Vascular prosthesis
Polyurethane	Blood contacting devices, Cardiac and vascular surgery, Facial prostheses
Poly vinyl chloride (PVC)	Blood vessels, Blood storage bags, Surgical drapes
Polymethylmethacrylate (PMMA)	Bone cement, Dental restorations, Intraocular lenses
Silicones	Soft tissue replacement, Ophthalmology
Hydrogels	Drug delivery, Ophthalmology
***Advantages*:** Easy to fabricate, low density/weight, ductile.	
***Disadvantages*:** Low mechanical resistance, easily degradable.	
Metals and alloys	
316L stainless steel	Fracture fixation, Stents, Surgical instruments
Ti, Ti-Al-V, Ti-Al-Nb,	Bone and joint replacement, Fracture fixation,
Ti-13Nb-13Zr, Ti-Mo-Zr-Fe	Dental implants, Pacemaker encapsulation
Co-Cr-Mo, Cr-Ni-Cr-Mo	Bone and joint replacement, Dental implants, Dental restorations, Heart valves
Ni-Ti	Bone plates, Stents, Orthodontic wires
Gold alloys	Dental restorations
Silver products	Antibacterial agents
Platinum and Pt-Ir	Electrodes
Hg-Ag-Sn amalgam	Dental restorations
***Advantages*:** High mechanical resistance to wear and shock, ductile.	
***Disadvantages*:** Low biocompatibility, prone to corrosion, difference in mechanical properties from biological tissues.	



Ceramics	
Alumina (Al_2O_3)	Joint replacement, in dentistry
Zirconia (ZrO_2)	Joint replacement, in dentistry
Calcium phosphates (Hydroxyapatite and Tricalcium phosphate)	Bone substituting r
Porcelain	Dental restorations
Carbons	Heart valves, Der devices

Table 1:



Biomaterial	*Medical applications*
***Advantages*:** High biocompatibility, corrosion and compression resistance, inert or bioactive, low thermal and electrical conductivity.	
***Disadvantages*:** Low impact resistance, difficulty in processing and fabrication, weak in tension.	
Composites	
Bisphenol A-glycidyl-quartz/ silica filler	Dental restorations
PMMA-glass fillers	Dental cements
***Advantages*:** High biocompatibility, corrosion resistance, inert, strong, tailor-made, distinctive properties.	
***Disadvantages*:** High production cost, lack of consistency, difficulty in reproduction during fabrication.	

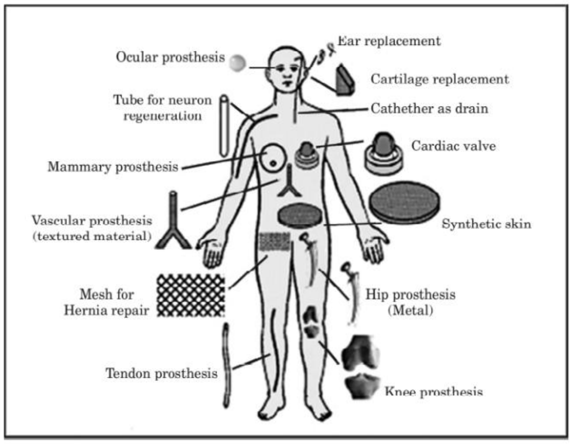
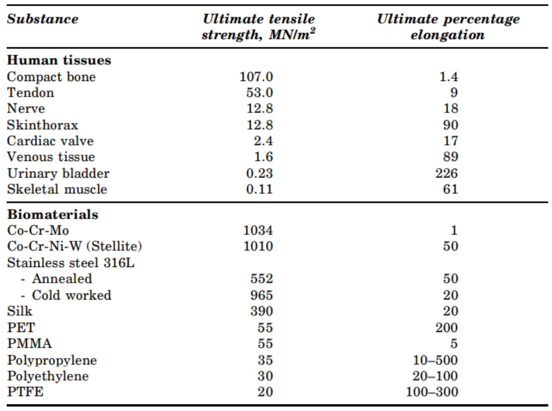


Fig. 1: Exemplary applications of biomaterials[10]

chemicals[11]. Except in orthopaedics, polymers are the most often used materials in biological and life science applications because of their excellent adaptability and compatibility with biological substances . Nano-Biomaterials: A Beginner's Guide [12] There are five cells. Polymers have been used in a wide variety of medical devices, from face prosthesis to tracheal tubes, kidney and liver organs to heart components, dentures to hip and knee joints, as adhesives and sealants in medical devices, and as coatings[7]. When it comes to metals, ductility, flexibility, malleability and high conductivity are some of the most often cited characteristics. Metals and their alloys are included in this. There must be at least one metallic element in an alloy to qualify as a metal[11]. Permanent metal implants made of stainless steel (316L), Cobalt-chromium (Co Cr) alloys, and commercially pure titanium (Ti) and titanium alloys have been used for decades because of their great tensile strength and fatigue resistance. Wires and screws may be used in a variety of ways, from basic fracture repair plates to prosthetic joints for hips and knee joints. Maxillofacial and cardiovascular surgery employ metallic implants, as well as dental materials[7].

Metal/semimetal with one or more nonmetals make up a ceramic substance, an inorganic combination. When compared to bone, ceramics have a greater elastic modulus, making them more brittle and difficult to work with. As a restorative material in dentistry for crowns, cements and dentures, ceramics have a high compressive strength but a poor tensile strength[13]. Ceramics have a smaller variety of medicinal uses than metals and polymers. Despite the fact that certain ceramic materials are employed in the field of joint replacement and bone augmentation, their low fracture toughness significantly restricts their usage in load-bearing situations. When two or more physically distinct phases are combined, the aggregate characteristics of the material are different from those of the individual components.[11] For decades, dental restoratives and dental cements made of composite biomaterials have been effectively employed. Composite materials are great for prosthetic limbs because of their lightweight density and high strength. However, despite the fact that their low elastic modulus has piqued researchers' interest, the carbon-carbon and polymer composites reinforced with carbon have yet to demonstrate the mechanical and biological qualities necessary for these applications[7]. The mechanical characteristics of various human tissues and biomaterials are summarised in Table 2.

Table 2: Mechanical properties of selected human tissues and biomaterials[14]



Substance	*Ultimate tensile strength, MN/m²*	*Ultimate percentage elongation*
Human tissues		
Compact bone	107.0	1.4
Tendon	53.0	9
Nerve	12.8	18
Skinthorax	12.8	90
Cardiac valve	2.4	17
Venous tissue	1.6	89
Urinary bladder	0.23	226
Skeletal muscle	0.11	61
Biomaterials		
Co-Cr-Mo	1034	1
Co-Cr-Ni-W (Stellite)	1010	50
Stainless steel 316L		
- Annealed	552	50
- Cold worked	965	20
Silk	390	20
PET	55	200
PMMA	55	5
Polypropylene	35	10–500
Polyethylene	30	20–100
PTFE	20	100–300

4. NATURAL BIOMATERIALS

A small reference of natural biomaterials is included in this article, which focuses on synthetic biomaterials. Using natural biomaterials for implants has many benefits over synthetic ones, the most significant of which is that natural biomaterials are more closely related to their host tissues than synthetic ones[7]. Tendons, ligaments, cartilage, bone, and skin all contain collagen, which is the most extensively utilised natural polymer. In the human body, there are at least 19 distinct kinds of collagen. There are three types of collagen: type I, which is found in skin, bone, and tendons; type II, which is found in joints; and type III, which is found in blood vessels[7]. Cowhide, which contains around half of all the protein in animals, is used to make the majority of commercial collagen products. Due to religious and consumer concerns about bovine spongiform encephalopathy (BSE) contamination, fish collagens have gained a lot of attention in recent years[15]. For example, algae have silicates; insects and crustaceans include chitin; humans possess keratin; trees contain cellulose; invertebrates possess diatoms; and vertebrates possess calcium phosphates.

5. RESPONSE OF A LIVING ORGANISM TO IMPLANTED MATERIAL

A foreign body response occurs when a biomaterial is put into the body (Fig. 2). These factors include the device's form and size, as well as its surface chemistry and roughness, electric charge, porosity, composition and hydrophobic or hydrophilic nature, sterility difficulties and contact time. Adsorption of proteins that cause cell adhesion is affected by these properties[17]. In every biomedical application, stem cell manipulation, nano biomedical devices, drug delivery systems, or gene transfer, the host's reaction to implant material is critical.[18].

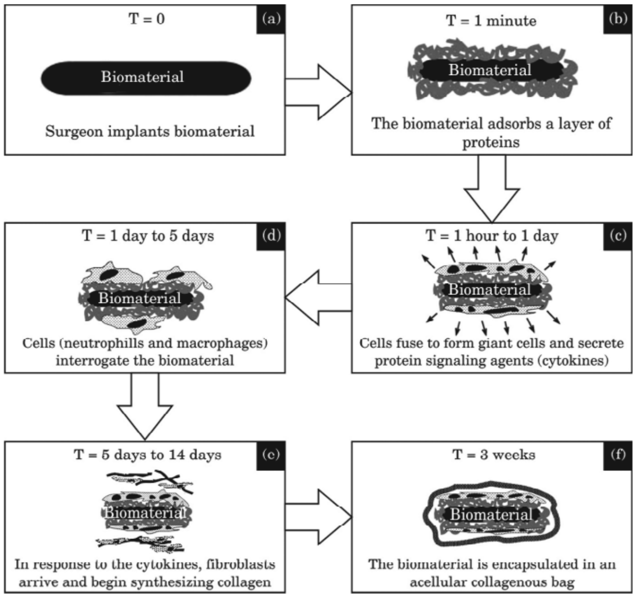


Fig. 2: Host response to an implanted biomaterial

A few nanoseconds after implantation, the tissue allows water molecules to come into touch with the implant material.a water layer forms around the implant when it comes into contact with the implant's surface. In the microenvironment, proteins and other molecules may adsorb onto the material surface thanks to the hydration layer that is there. Seconds to hours after implantation, the material is covered by a thin layer of the extracellular matrix proteins, a process that takes place in the second stage. As soon as a few days after implant placement, cells begin to interact with the implant surface via the protein layer that has been adsorbent[19]. Implant biomaterial is examined and attacked by neutrophils and macrophages. macrophages merge to generate large cells to eat the implant when they can't break it down on their own. However, since the implant is too big to be phagocytosed by adherent macrophages, persistent inflammation develops at the implant-to-body interface. This time, the cytokines are released by the large cells to attract more cells. Collagen production begins as soon as the fibroblast cells arrive. A vascular, collagenous fibrous capsule, ranging in thickness from 50 to 200 m, forms as the ultimate step of the foreign body response. The implanted device is contained inside a fibrous capsule, which prevents it from interacting with the tissues around it[20].

6. NANOSTRUCTURED BIOMATERIALS

For example, nanostructured biomaterials including nanoparticles, nanofibers, nanosurfaces, and nanocomposites, as well as other relevant biomedical applications, have received a lot of interest. Nano-sized or nano-structured biomaterials are made from polymers, metals, ceramics, and composites. Fig. 3 depicts the many methods utilised to create nano-sized biomaterials. The core of nano biomaterials is generally a nano-particle. Spherical, cylindrical, and plate-like forms are all possibilities, although the most common shape is spherical. It is possible that the core has several layers and multiple functions. By combining magnetic and luminous layers, for example, one may detect and manipulate the particles. One layer of silica or another inert substance covers the core particle in most cases. Organic compounds that are adsorbed or chemisorbed on the particle's surface also play a role in this process. Alternatively, the same layer may be a biocompatible substance. Additional linker molecules are often needed, however, in order to continue with further functionalization. On both ends of this linear linker molecule, you'll find reactive group(s). The linker is attached to one group's project.

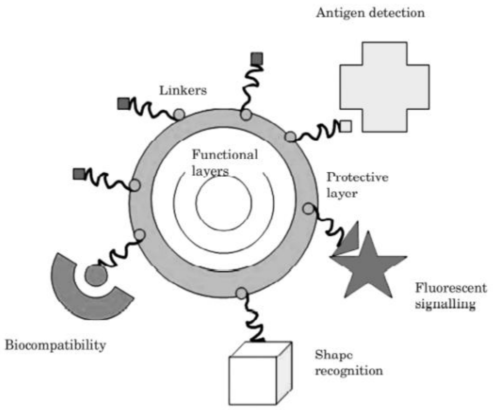


Fig. 3: Schematic diagram showing construction of nano-biomaterials[21]

[21] The nanoparticle surface and the other is employed to bind different moieties such as biocompatibles (dextran), antibodies and fluorophores, depending on the function needed for the specific application. There are a number of surface modification approaches that may be used to create nano-structured surfaces on traditional biomaterials. Many techniques are used to deposit coatings and films on metal surfaces. These include plasma spraying, immersion ion implantation and deposition in plasma, sol-gel deposition, cold spraying, self-assembly, and a variety of other methods. In situ surface modification methods include laser etch and blast treatments as well as acid and alkali treatments as well as micro-arc treatment and anodic oxidation[5].

7. CONCLUSIONS

It has been more than 60 years since the area of biomaterials and medical devices began to develop and grow. New avenues for the development of nano biomaterials have been opened up as a result of the rise of nanotechnology as a significant scientific discipline and the integration of biology. For example, the high activity of nano-biomaterials is due to their structural imperfection, which makes them valuable in a variety of medical applications, but they also have great potential for biological dangers, which should be researched further. Biomaterials and nano-biomaterials have been briefly discussed in this article. The reader is recommended to many good research and review publications utilised in the development of this article for a more in-depth discussion of the synthesis, characterisation, surface functionalization, and medicinal uses of these materials.

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