

BIOMATERIAL AND ITS MEDICAL APPLICATIONS

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ABSTRACT

A Biomaterial is any natural or synthetic material that is used to replace or restore function to a body tissue and is continuously or intermittently in contact with the human body. These materials do not completely replace function of the human tissues but they possess an adequate level of physical and mechanical properties to serve for the replacements of body tissues. Biomaterial has properties such as biocompatibility, slower phase of degradation, mechanical strength. Utilization of polymers as biomaterials has greatly impacted the advancement of modern technology in medical field. In specific, polymeric biomaterials that are biodegradable provide the significant advantage of being able to be broken down and removed after they have served their function. The above mentioned properties are very essential in order to use it as a biomaterial in medical field. Some of the predominant applications of biomaterial are tissue engineering, drug delivery system, wound healing, cardiovascular application. Property of biomaterial is a very important factor that makes it essential for the desired end uses. In this paper, properties and applications of some of the biomaterials are discussed.

Keywords:- Biomaterials, Biopolymers, Hydrogels, Biocompatible, Biodegradable.

1. INTRODUCTION

Biomaterial is used to make devices to replace a part or a function of the body in a safe, reliable and physiologically acceptable manner. Biomaterials are made as a structure or device or a material that are used for repairing a tissue or using as an implantable material for the desired applications [1]. They can be either made from a natural origin or synthetic origin. Based on the origin of materials, they have been classified into different types. They vary with their physical, chemical, mechanical and mainly biological property [2]. Nowadays various developments are done for bringing up the naturally originated biomaterials since they are basically eco-friendly and easily biodegradable [17]. These materials (biomaterials) presently can be used for the treatment of a disease or an injury [2]. These materials are biocompatible and biodegradable in nature which makes it fit for the medical applications. Biomaterials are used on the host body which has no diverse effects. The different materials or devices that are used include sutures, needles, catheters, artificial tissue, etc [3][17]. Biomaterials have been developed in the few decades which are used as an organ in a living system or to function along with the living tissues [4]. The different biomaterials that are used mainly are metallic, ceramic, polymeric, and composite biomaterials [5]. Each material has their diverse property that helps them to survive in the particular applications.

2. TYPES OF BIOMATERIALS

There are different types of biomaterials which are synthesized and used for different applications. The various types of biomaterials are discussed below:

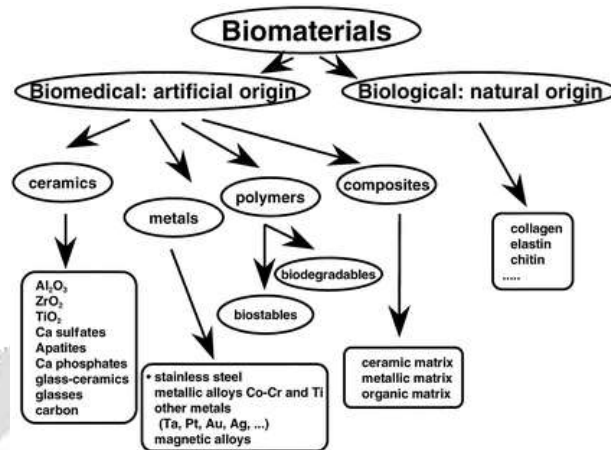


Fig -1: Classification of Biomaterials

Table-1: Biomaterials and their advantages and disadvantages

Materials	Advantages	Disadvantages	Examples
Polymers (nylon, silicon, polyester)	Resilient Easy to fabricate	Not strong Deform with time May degradable	Suture, blood vessels, hip sockets
Metals (Ti and its alloys, Ag, Au, stainless steels)	Strong, tough, Ductile	May corrode Dense Difficult to prepare	Joint replacement, dental root implant, pacers, bone plates and screws
Ceramics (alumina, zirconia, hydroxyapatite)	Very Biocompatible	Brittle Not resilient	Dental and orthopaedic implants
Composites (carbon-carbon, bone cement)	Strong Tailor made	Difficult to prepare	Dental resin, bone cement

2.1. Types of biomaterials

2.1.1. Metallic biomaterials

Metallic biomaterials are mainly used in the applications where the load bearing property is concerned namely the application of knee implants, fracture and dental applications [5][9][18]. These materials can be used in various medical applications due to their excellent and prevailing mechanical properties [6]. The most commonly used metallic biomaterials are stainless steel, Cobalt-chromium molybdenum and the Titanium alloys [2]. Even though these materials have greater mechanical properties they easily get corroded in a few periods after their implantation in the host [8] [19]. It also has a very important disadvantage called the toxicity. These properties finally start to affect the living system where they are implanted. These in combination will destroy the properties of the implant leading to the deterioration of the implants and finally resulting in the reduction of their biocompatibility [15]. Thus it leads to a failure at some situation. The metallic biomaterials have to be

selected based on the surrounding condition of the host system. Based on the surrounding condition of the implants in the living body they have to be selected and used without causing any diverse effects to the living system. Hence only with the desired raw materials which suits for the implant and the ambient condition of the host, the problems occurring from these materials can be avoided thus resulting in a betterment of the biomaterials and decrease in the problems related to the material.[16][27].

Table-2: Biomaterials and its specific applications

Types of Materials	Applications
Stainless steel	Joint replacements (hip, knee), Bone plate for fracture fixation, Dental implant for tooth fixation, Heart valve, Spinal Instruments, Surgical Instruments, Screws, dental root Implant, pacer, fracture plates, hip nails, Shoulder prosthesis
Cobalt-chromium alloy	Bone plate for fracture fixation, Screws, dental root implant, pacer, and Suture, dentistry, orthopedic prosthesis, Mini plates, Surgical tools, Bone and Joint replacements (hip, knee), dental implants
Titanium and its Alloys	Cochlear replacement, Bone and Joint Replacements(hip, knee),Dental Implants for tooth fixation, Screws, Suture, parts for orthodontic surgery, bone fixation devices like nails, screws and plates, artificial heart valves and surgical instruments, heart pacemakers, artificial heart valves

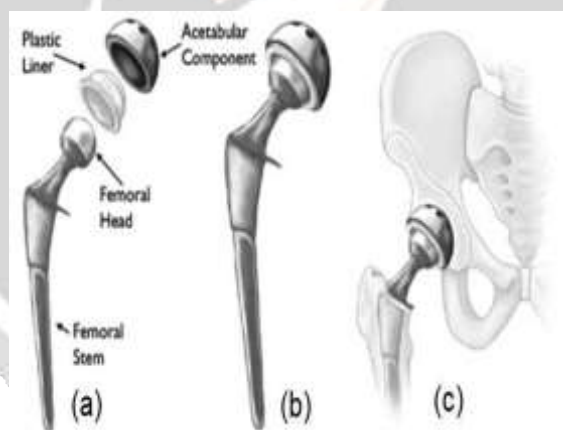
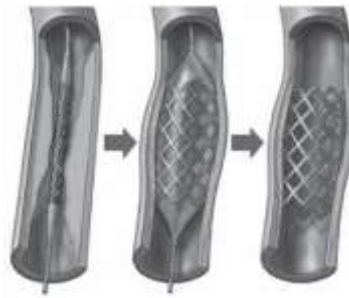


Fig-2: (a)Components of a total hip replacement; (b) The components merged into an implant; (c) The implant as it fits into the hip.



Fig-3: Biomaterials as a dental implant**Fig-4: Polymeric biomaterials for load bearing applications**

2.1.2. Ceramic biomaterials

Ceramic materials are generally biocompatible, very high resistant to corrosion, compression with low electrical and thermal conductivities [5][26]. Ceramic biomaterials are mostly suited for the medical implants [11]. It has a very low toxicity and helps in the higher efficiency in forming new bone tissue. In ceramics, some examples include calcium phosphate which mainly helps in tissue regeneration and also used for bone repairs; hydroxyapatite is mainly used as dental implants due to their excellent hardness properties [13]. This material comprises metallic and non – metallic components in their structure. They are highly inert in nature, hard and brittle which has a high compressive strength but a poor tensile strength [14]. These materials are mainly used in Orthopaedic implants and dental applications [9] Natural hard tissues comprises of ceramic – polymer composites. e.g. bones and teeth. Ceramic biomaterials based on their bioactivity it is used in different medical applications. [10][13] For e.g. Fully degradable materials are used in the clinical applications such as drug delivery. Nanostructured ceramics are developed in present day in a very great manner. Thus application of ceramic materials varies according to the end uses.

**Fig-5: Ceramic biomaterials in drug delivery**

2.1.3. Polymeric biomaterial

Polymeric biomaterial is considered as one of the best materials for the medical end uses. When compared to metallic and ceramic biomaterials, these materials are widely used in various aspects [7]. Synthetic polymeric materials have been widely used in medical disposable materials, prosthetic materials, dental materials, implants, dressings, polymeric drug delivery systems, tissue engineered products, like those of metal and ceramics substituent [9]. The main advantages of the polymeric biomaterials compared to metal or ceramic materials are ease of manufacturing to produce various shapes (latex, film, sheet, fibres, etc.), ease of secondary processing stages, reasonable cost, and availability with desired mechanical and physical properties [6]. The required properties of polymeric biomaterials are similar to other biomaterials, that is, biocompatibility, biodegradability, sterilizability, adequate mechanical and physical properties, and manufacturability [7][19]. There are various polymeric materials used that are mentioned below.

3. BIOPOLYMERS

A huge application use biopolymers in various aspects. Enormous developments in the field of biopolymers are still made which is thus considered as an evolutionary process [2]. Most of the applications use natural biopolymers than using synthetics [7]. The main properties of biopolymers are their biodegradability, biocompatibility, light weight, flexibility, resistant to biochemical attacks [1]. These properties make them unique in their application aspects in medical field. A variety of polymers have been used for medical care including preventive medicine, clinical inspections, and surgical treatments [19].

Table-3: Biopolymers and its significant applications

Application	Shape	Example
Binding materials	Suture, clip Adhesive	Poly(α -hydroxy acids), poly(1,4-dioxan-2-one), polyglyconate, collagen Poly(α -cyanoacrylate)
Bone-setting materials	Plate, screw, rod, pin, splint	PLLA, polyglactin, hydroxyapatite
Hemostatic materials	Wool, dressing, powder, spray	
Antiadhesion materials	Sheet, jelly, spray	Gelatin
Matrix for tissue culture	Sponge, mesh, nonwoven fabrics, tube	
Artificial tendon and ligament	Fiber	PLLA, polyglactin (combined with carbon fiber)
Artificial blood vessel	Fiber, porous material	PLLA, polyglactin
Wound cover attributes	Fiber	Collagen, chitin, polyglactin, poly-L-leucine
Synthetic skin	Fiber	Collagen
Drug delivery system	Microcapsule, microsphere, needle, hollow fiber	All degradable polymers

Among the polymers employed for such medical purposes, a specified group of polymers are called polymeric biomaterials when they are used in direct contact with living cells of our body. Application of biopolymer has become drastically very high in the few decades [22]. The statistical data of the contribution of the biomaterial has been mentioned below.

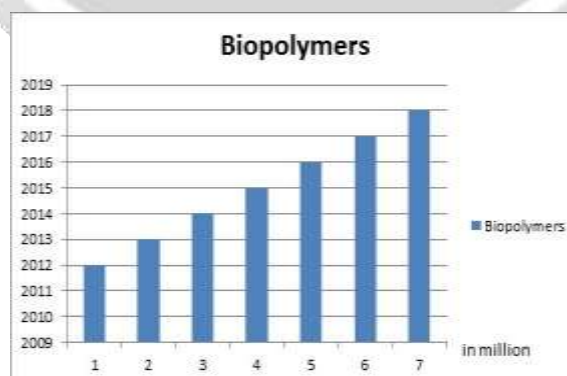


Chart-1: Biopolymer market growth

Some of the typical biopolymers are discussed below.

3.1. Poly(lactic acid) (PLA)

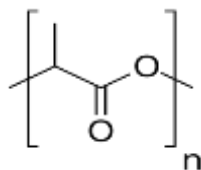


Fig-6: Structure of Polylactic acid (PLA)

PLA is thermoplastic aliphatic polyester, biodegradable. It is derived from renewable resources by means of a fermentation process using sugar from corn, followed by either ring-opening polymerization or by condensation polymerization of lactic acid. It is one of the most important biocompatible and biodegradable polymers in a group of degradable plastics [20]. In addition to its application in textile industries, automotive and clinical uses, PLA represents a good candidate to produce disposable packaging due to its good mechanical properties and process ability [24]. For load bearing applications, PLA is the most used polyester due to its intrinsic high mechanical strength [21]. PLA is used in internal fixation devices, such as screws, plates, pins, and rods to support the repair of broken bones and hold them together [20].

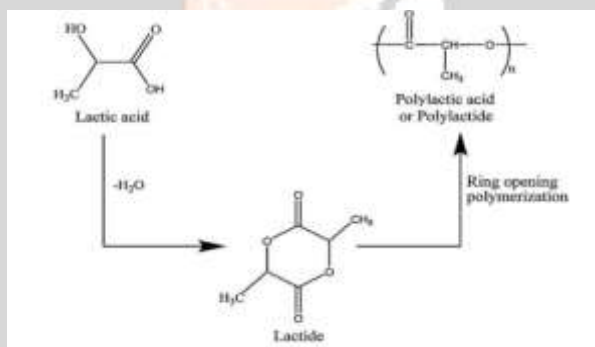


Fig-7: Production of PLA polymer

3.2. Polyhydroxyalkanoate (PHA)

Polyhydroxyalkanoates (PHA) or polyhydroxyalkanoic acid, the main kind of biodegradable and biocompatible biopolymer, are classified as linear polyesters. They are naturally produced by bacteria in general cultivated on agricultural raw materials. They can be processed to make a variety of useful products, where their biodegradability and naturalness are quite beneficial in particular for application in single use packaging and agriculture. It has its promising properties such as high biodegradability in different environments, not just in composting plants, and processing versatility. Indeed among biopolymers, these biogenic polyesters represent a potential sustainable replacement for fossil fuel-based thermoplastics. Most commercially available PHAs are obtained with pure microbial cultures grown on renewable feedstock (i.e. glucose) under sterile conditions but recent research studies focus on the use of wastes as growth media. PHA can be extracted from the bacteria cell and then formulated and processed by extrusion for production of rigid and flexible plastic suitable not just for the most assessed medical applications but also considered for applications including packaging, moulded goods, paper coatings, non-woven fabrics, adhesives, films and performance. PHA and its copolymers are widely used as biomedical implant materials which include sutures, bone plates, meniscus repair devices, cardiovascular repair patches and stem cell growth. It is used in drug delivery applications due to its biocompatibility and controlled degradability.

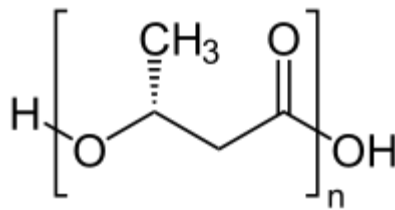


Fig-8: Structure of Polyhydroxyalkanoate (PHA)

3.3. Polyvinyl Alcohol(PVA)

Polyvinyl Alcohol (PVA) is a synthetic, biocompatible and toxicologically safe polymer that is exceptionally well suited for a variety of applications. . PVA is biocompatible, toxicologically safe, water-soluble and suitable for simulation of natural tissues. It has good oxygen permeability, shows no immunogenic effects, and features excellent film forming, emulsifying and remoistable properties.

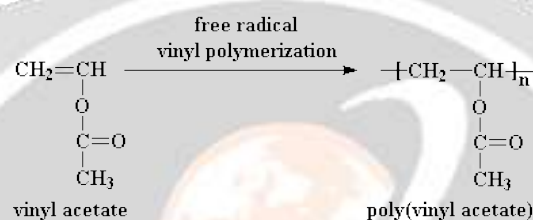


Fig-9: Process of free radical vinyl polymerization

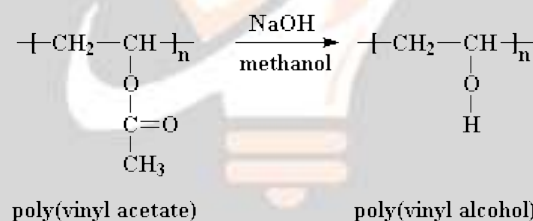


Fig-10:Formation of polyvinyl alcohol.

3.3.1. PVA Hydrogels

Hydrogels are three dimensional cross linked hydrophilic polymers with the ability to absorb water or aqueous solutions into their structure [29]. Hydrogels are those that swollen with the water. These are referred as the hydrophilic gel which is sometime known as colloidal gels [30]. Depending on the degree of chemical or physical cross linking, the amount of absorbed water varies as such they can be classified as low, medium, and high swelling hydrogels [31]. PVOH hydrogels, due to their susceptibility to hydrogen bonding and excessive crystallization, generally offer very low swelling capacity, making them however very desirable for specific biomedical and pharmaceutical applications[32]. Due to their simple structure and unique properties such as adhesiveness, strength, film forming, biocompatibility, swelling, safety, and non-carcinogenicity, PVOH polymers have found applications in different industries including textile, paper, adhesives, food, biomedical and pharmaceutical applications in particular[32]. Properties such as high water content, elastic nature in the swollen state, biocompatibility, and swelling make the PVOH hydrogels a potential candidate as tissue replacement material. The PVOH hydrogels have been studied as soft contact lens material, artificial heart linings, artificial cartilages, catheters, skin, and pancreas membranes [31]. In previous studies of PVOH hydrogels for biomedical applications, physical and gel properties were studied, and blood compatibility was the primary concern for the researchers. PVOH hydrogels prepared at low temperature crystallization, in particular, were studied as soft contact material, and displayed better optical properties, high oxygen permeation and low

protein absorption than regular contact materials. Because of their biocompatibility, drug compatibility, water solubility, film forming, good mechanical and swelling properties, the PVOH hydrogels have been studied as drug delivery systems in oral, transdermal, intra- muscular, rectal routes of administration[32]. Degree of crystallinity plays a major role in controlling diffusion of the drug from Hydrogels.

In general, PVOH hydrogels can be designed either as matrix or reservoir drug delivery platforms. Altering gelling properties, solubility, adding copolymers have also been utilized to control the drug release from PVOH Hydrogels

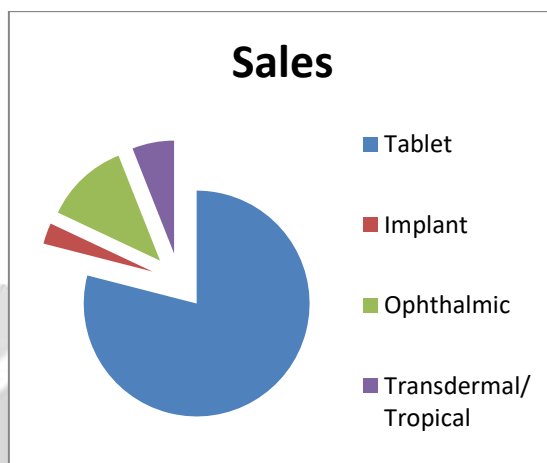


Chart-2: Market sales of PVA Hydrogels

3.4. Polycaprolactone

Synthetic polymers with biodegradable and biocompatible properties are becoming very important in medical applications. One such polymer is Polycaprolactone. It is biodegradable polyester which is preferred for its biocompatibility. It is mainly used for drug delivery [21]. This polymer is finding its special place in medical application due to the prolonged degradation time. Polycaprolactone is known for its low melting point. Hence it can be easily reshaped according to the end uses [28]. It is resistant to water, solvents and oils. It is used in long term implantable devices for drug delivery. It is degraded by the hydrolysis of ester linkage in physiological conditions. It is used in sutures, scaffolds and vesicle membranes. Drugs have been encapsulated into PCL for targeted drug release. It is also used in the manufacture of speciality polyurethanes. Polycaprolactone is produced by the ring opening polymerization of the monomer epsilon-Caprolactone (CL) [28]. CL is a closed ester which belongs to the lactone family, comprises of seven membered ring. Ring opening polymerisation leads to production of Polycaprolactone. This process is conventionally catalysed by metallic components. It is difficult to remove the catalysts after the reaction and they are also toxic to the human body. Hence an alternate route of using enzymes as catalysts is being employed to reduce the toxicity. This method is economical as the enzymes used can be regenerated as such at the end of the reaction and can be reused.

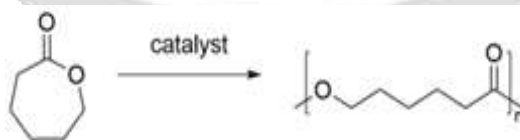


Fig-11: Ring Opening Polymerisation of Caprolactone.

3.5. Polyglycolide

It is one of the first biodegradable synthetic polymers used for medical applications. Polyglycolide is a highly crystalline polymer and therefore exhibits a high tensile modulus with very low solubility in organic solvents. In spite of its low solubility, this polymer has been fabricated into a variety of forms and structures. Extrusion, injection and compression moulding as well as particulate leaching and solvent casting, are some of the techniques used to develop polyglycolide-based structures for biomedical applications. [33] Due to its excellent fibre forming ability, polyglycolide was initially investigated for developing resorbable sutures. Non-woven

polyglycolide fabrics have been extensively used as scaffolding matrices for tissue regeneration due to its excellent degradability, good initial mechanical properties and cell viability on the matrices. [33] A polyglycolide non-woven fabric-fibrin glue composite matrix is currently undergoing clinical trials. It is being investigated as a biocompatible dural substitute due to its excellent skin-closing ability without requiring sutures and its ability to help regenerate biological tissue. Due to its good initial mechanical properties, polyglycolides have been investigated as bone internal fixation devices. The high rate of degradation, acidic degradation products and low solubility however, limit the biomedical applications for polyglycolide. Therefore, several copolymers containing glycolide units are being developed to overcome the inherent disadvantages of polyglycolide.

4. CONCLUSION

Biomaterials have been developed in a wide range mainly based on its properties and biomedical applications. It has made a great impact in various medical applications. Biodegradable polymers can be produced from various renewable resources that is eco- friendly. It has some drawbacks but it does not affect the commercial applications in wider manner. The advantage of the bio – based polymers is that it has better performance in their bio medical property. Various advancements have been made in the development of the biopolymers and in the betterment of the properties of those biomaterials in the desired applications.

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