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Biodegradable Polymers

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INTRODUCTION

The same durability properties which make plastics ideal for many applications such as in packaging, building materials and commodities, as well as in hygiene products, can lead to waste-disposal problems in the case of traditional petroleum- derived plastics, as these materials are not readily biodegradable and because of their resistance to microbial degradation, they accumulate in the environment. In addition in recent times oil prices have increased markedly. These facts have helped to stimulate interest in biodegradable polymers and in particular biodegradable biopolymers. Biodegradable plastics and polymers were first introduced in 1980s. There are many sources of biodegradable plastics, from synthetic to natural polymers. Natural polymers are available in large quantities from renewable sources, while synthetic polymers are produced from non- renewable petroleum resources.

The alarming awareness related to environmental and waste management issues around the universe, status and negative effects of fossil resources, are some of the reasons why biodegradable polymers and the need for their usage is increasingly promoted for sustainable development. Moreover, there is no sustainable economic development without a sustainable environment. Researchers universally have proven that fossil resources pose a serious threat to existence of humans, plants and animals by the generation of greenhouse gases and CFC's. Critically observing the scenario, there is no need to exaggerate the importance of the safe and healthy environment to universal sustainable development. It is a prerequisite on which human and other living things existence lies. Biodegradable biopolymers from research results do not pose such a threat to the environment and its inhabitants compared to fossil based polymers, and therefore, there is need for biodegradable biopolymers universally.

The cost of biopolymers needs to be looked into objectively and addressed, because as biopolymer is developing, more ideas about biopolymers and the need to embrace their usage is necessary and important, therefore, Economic concerns must be addressed, because the future of each biopolymer product is solely
dependent on its cost competitiveness, and society's ability to pay for it because most of the biopolymers are costly and since petroleum based polymers are cheaper, industries embark on their usage without considering the environmental factors rather the profit. In developed and developing countries, governments and
NGO'S are introducing initiatives designed to promote, enlighten people and promote education by giving research grants, provide room for application and adequate development of biopolymers. Most countries all over the world and their policy makers support work in the area of biopolymer research, with government's universally interested e.g. German government being particularly interested.[3] This literature review provides information providing awareness and progress made available in the production, application and development of biodegradable polymer materials and some important information needed to be explored about biodegradable materials.

HISTORY

Polylactic acid polymers were first investigated in the 1930s by Caruthers at DuPont. Many researchers investigated polylactic acid and polylactides over the next 50years. Cargill developed the technology for making lactides and purifying them with distillation while controlling the optical composition and purity of the lactides. This allowed Cargill to harness the polymer property variations that various lactide optical properties provide to polylactide polymers.

Among these materials, biodegradable polymers play an important role, especially for bone regeneration and periodontal surgery. However, only a few biodegradable polymers are currently established in clinical applications mainly because of

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i) the difficulty to modulate the degradation rate of implanted samples,

ii) the existence of byproducts, and

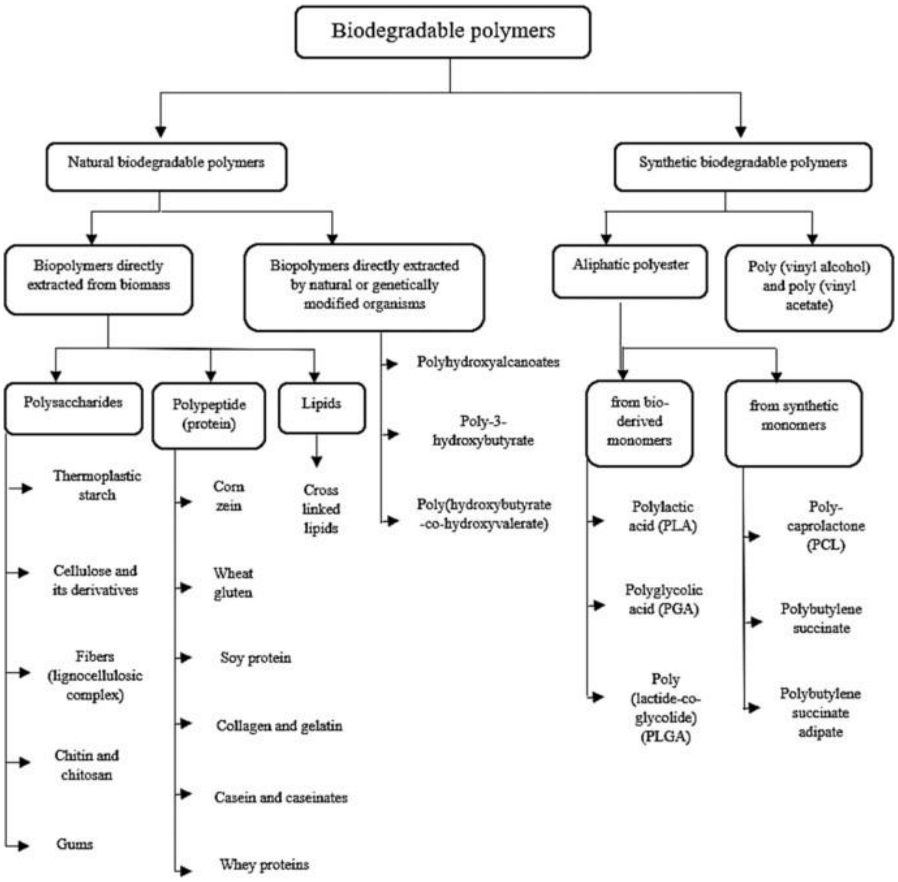
iii) the difficulty sterilizing them and preserving the mechanical and chemical properties designed for the applications sought.

Biodegradable materials should be designed to support cell proliferation and differentiation up until tissue healing and regeneration. Afterwards, they should be eliminated from the body, in order to avoid parenteral storage of long-lasting foreign compounds. Many synthetic materials made of metals (e.g., magnesium alloys), ceramics, and polymers meet these requirements and therefore may be promising for periodontal or bone re-generation. For example, calcium-phosphate or calcium- carbonate ceramics, aliphatic polyesters, co-polyesters, and natural-derived polymers are nowadays extensively clinically applied.

Attributes of an ideal polymer

- Should be adaptable and have an extensive variety of mechanical, physical, substance properties.
- Should be non-lethal and have great mechanical quality and ought to be effectively regulated.
- Should be economical.
- Should be anything but difficult to create.
- Should be idle to host tissue and perfect with environment.

CLASSIFICATION OF BIODEGRDABLE POLYMERS[



Polymers obtained from biomass

STARCH

Starch is the major form of carbohydrate storage in green plants and is considered the second largest biomass produced on earth. Starch is a cheap and easily available raw material, which is present in large quantities in potatoes, maize, rice and wheat.

In natural form, starch is not meltable and cannot be processed as thermoplastic[6]. Starch granules can be thermoplasticized through a gelatization process, where the granules are disrupted, and the ordered crystalline structure is lost under the influence of plasticizers, shears and heat. The resultant melt-processable starch is called thermoplastic starch (TPS).

Bioplastics based on starch are suitable for the production of packaging, in agriculture, for medical and cosmetic application.

Namely, the disposed pressure-sensitive adhesive tape widely used in daily life has been contaminating the environment and has produced vastly non-degradable trash. Czech et al. studied the advanced biodegradable pressure-sensitive double- coated tape containing starch carrier and water-soluble partially degradable modified pressure sensitive adhesive. They observed the excellent tack and peel adhesion of these newly constructed biodegradable self-adhesive tapes, and high thermal shear strength . The complete biodegradability of starch carrier and partial biodegradability of modified acrylic PSA were confirmed . This environmentally friendly technology based on the starch has great potentials for diverse applications such as the paper industry for manufacturing of ecological biodegradable product, the production of water-soluble biodegradable labels, medical tapes and biomedical electrodes

CELLULOSE

Cellulose is the most widespread natural organic polymer, representing about 1.5×10^{12} tonnes of total annual biomass production and is considered an almost non- exhaustive source of raw material for increased need for environmentally friendly products. The primary source of cellulose is the existing lignocellulosic source in forests.

Cellulose fibers are used to produce biodegradable packaging materials, in cosmetic products without synthetic polymers or strong composites together with biodegradable plastics

Nanofibrilated cellulose (NFC) has an incredible potential as reinforcement material in nanocomposites for many different uses, such as foams and adhesives. Missoum et al. [8] prepared NFC and their derivatives using three chemicals surface modification strategies. Antibacterial activities of all samples were investigated against two kinds of Gram^{+} bacteria (Staphylococcus aureus) and Gram^{-} bacteria (Klebsiella pneumoniae). They also strongly enhanced the photo- catalytic antimicrobial effect of TiO_2 additive. This study shows that it is better to use grafted NFC either alone or functionalized with TiO_2 if anti-bacterial properties are desired.

Hydrogels are defined as three-dimensional macromolecular structures, able to retain a considerable aliquot of solvent without to be solved. Several polymers have been used as a base for hydrogel development: methacrylate, hyaluronic acid, alginate, gelatine, polyglycerol, methylcellulose, carboxymethylcellullose, etc.

Hydrogels have numerous applications, that range from industrial (food, chemical, mechanical) to biomedical uses. In particular, hydrogels are a very interesting new class of biopolymer because they are biocompatible, degradable, and hydrophilic. All these features enable considering hydrogels as very similar to human soft tissues.

Today, the literature reports a number of papers presenting hydrogels as polymer for tissue engineering in the cell housing in the brain and spinal cord, nerve repair, bone and cartilage replacement, and heart diseases. Hydrogels have also recently been proposed as carriers for drug and protein delivery

(Methyl cellulose) MC-based hydrogels could be classified as “smart” polymers: this particular class of polymers has the characteristic of modifying its chemical- physical state only by responding to an external stimulus, such as pH variation, mechanic, electric, magnetic or bright signal, and temperature . As reported above, MC-based hydrogels respond to temperature changes, ranging between a liquid-gel phase and a solid-gel phase. It is very important to underline that the temperature-dependent phase transition is reversible: MC hydrogels are not only thermo-responsive polymer, but they are also thermo- reversible polymers. In particular, the transition from liquid to solid phase is recognized at approximately 32ºC; it means that MC hydrogels could be used as a scaffold for cell growth, that requires a temperature of 37°C . Depending on MC concentration, it is possible to obtain soft or strong solid gels that enable cultivating cells on the surface or inside the hydrogels.

SOY PROTEINS

Soy is a cheap, and renewable source of biopolymers, which has a great potential to replace petrochemical polymers in many applications. Soy protein (SP) is commercially available in three various SP concentrations: soy flour (54 %), soy concentrate (65-72 %) and soy isolate (90 %) For medical purposes Tansaz et al. investigated the fabrication of SP isolate/nanoscale bioactive glass composite films by solvent casting method as a matrix for wound-dressing applications. The effect of the addition of bioactive glass nanoparticles on blood clotting was assessed. The composite films could meet the essential requirements for an appropriate wound dressing with additional favorable properties such as hemostatic capability, mechanical properties and significant cell cytocompatibility.

Chitin is a structural biopolymer, which has a role similar to that of collagen in higher animals and cellulose in plants. Plants produce cellulose in their cell walls and insects and crustaceans produce chitin in their shells. Cellulose and chitin are, thus, two important polysaccharides that provide structural integrity and protection to plants and animals, respectively. This function must be related to a unique structure. In fact, chitin may be regarded as cellulose with the hydroxyl group at position C-2 replaced by an acetamido group, while chitosan is the N-deacetylated derivate of chitin.

Chitosan is considered as an appropriate functional material for biomedical applications because of its significant biocompatibility, biodegradability, nonantigenicity, and adsorption properties. Anti-inflammatory or allergic reactions have not been observed in human subjects following topical application, implantation, injection, and ingestion. The ability of chitosan to support cell attachment and proliferation areattributed to its chemical properties. The polysaccharide backbone of chitosan is structurally similar to glycosaminoglycans, the major component of the extracellular matrix of bone and cartilage. Other advantages of chitosan scaffolds for bone tissue engineering includes the formation of highly porous scaffolds with interconnected pores, osteoconductivity, and the ability to enhance bone formation both in vitro and in vivo,

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Biopolymers	Materials	Area of Applications
PLGA (Poly(lactic-co-glycolic acid))	Polyethylene glycol/PLGA	Advanced cellular uptake and hypoglycemic effect on oral administration.
	Polysorbate-80-coated PLGA	Reduced hemolysis, improved antioxidant activity
	paclitaxel loaded PLGA nanoparticles	Enhanced internalization, and targeting potential
	Polysorbate-80-coated PLGA	Enhanced mechanism of drug delivery, diminished drug dosage, and side effects
PLA (Polylactic acid)	Docetaxel loaded PEG-PLA	Enhanced cytotoxicity and apoptosis
	Docetaxel loaded PLA	Momentous decrease in tumor size and cell proliferation
	Tamoxifen loaded PLA	Noteworthy decrease in renal toxicity, hepatoxicity, and immunogenic side effects
	Glimepiride loaded PLA	Improved continuous drug release effect
	Folate-conjugated albumin	Enhanced target-site potential to the

Biodegradable polymers obtained via microbial production

POLYHYDROXYALKANOATES (PHAS)

PHAs are classified as natural aliphatic biopolyesters, synthesized by many different bacteria as intracellular carbon and energy storage materials.

PHAs have the ability to combine more than 150 monomers to produce materials with very different properties and functionalities. Mechanical and biological compatibility can be altered by mixing, altering the surface, or by combining PHA with other polymers, enzymes or inorganic materials, allowing them a wider spectrum of use. The main areas of PHA use include packaging (containers and films), coatings, pharmaceutical and medical applications (wound dressings, medical devices, orthopedic pins, stents, nerve guides and bone marrow scaffolds). Besides, PHAs are used as hardeners in cosmetic products, hygiene products, toners and adhesives, electronic issues and golf balls. PHA plastics are in contrast to other types of bioplastics (eg. PLA), UV stable, can withstand temperatures up to 180 °C and are poorly water permeable.

PHAs have emerged as highly promising biomaterials both for bulk and biomedical applications. Wound management, coronary angioplasty, nerve regeneration, bone tissue engineering, cardiac tissue engineering and drug delivery are some examples of biomedical applications where PHA-based materials have been explored.

Aliphatic polyesteres and co-polyesters

Biodegradable synthetic polymers such as poly (lactic acid), poly (glycolic acid), and their copolymers have been applied in numerous clinical fields. They offer many advantages: they can be tailored with the desired shape, pore morphology, and three-dimensional structure and they can be degraded into the body producing natural metabolites. Their major applications include resolvable sutures, drug delivery systems, and orthopedic fixation devices such as pins, rods, and screws

Poly (lactic acid) (PLA), is a biodegradable polyester derived from the polymerization of lactic acid. It can be produced by chemical synthesis or fermentation. PLA has many applications, such as packaging and textile, but it has also been applied to biomedical and drug-delivery systems fields. The properties of PLA depend on the component isomers, which influences characteristics such as crystallinity and consequently biodegradation: poly-L- lactide (PLLA) is the product resulting from polymerization of L-lactide, while poly-D-lactide (PDLA) derives from the polymerization of D-lactide. They both present a strong hydrophobicity, which makes them insoluble in water.

For its applications in regenerative medicine, PLA is often copolymerized with other monomers, in order to increase its biological properties. Moreover, its surface can be modified by functionalization with different molecules such as polysaccharides or proteins or by coating with molecules which increase cell adhesion.Polyglycolic acid, (PGA), is another biodegradable polymer widely used for absorbable sutures and orthopedic pins. It provides excellent support for tissue development. However, it has been reported that its degradation in the body leads to an inflammatory response.

Polylactide-co-glycolide (PLGA) is the copolymer of PLA and PGA.

It is widely used in many biomedical fields, because of its degradation in the body into nontoxic products and because it can be shaped into the sought-after structure and porosity. In order to investigate its degradation and the localization of its products into cells, it has been linked to a fluorescent dye. Dye- loaded nanoparticles of PLGA have also been synthesized for diagnostics applications, promising a suitable product for degradable photo-acoustic contrast agents. Moreover, PLGA micro particles have been loaded with proteins such as BMP-7 in order to release proteins during their degradation and to increase their osteogenic potential

Biopolymers derived directly from naturally occurring or genetically engineered organisms

Microorganisms are a source for research on bioplastic materials and biopolymers that use agricultural wastes as a medium for growth. Example of microbiological compounding plastic is polyhydroxyalkanoate (PHA), which is produced from various groups of bacteria and cheap renewable resources. It is completely aerobic decomposed by microorganisms. polyhydroxyalkanoates are produced from a biodegradable aliphatic polyester family. They are formed in nature and produced directly by bacterial metabolism. They are genuinely biodegradable and profoundly biocompatible thermoplastic materials and can be developed from a variety of renewable resources. Polyhydroxyalkanoate is the potential alternative to the non- degradable polyethylene and polypropylene. Poly(3-hydroxybutyrate) (PHB) is the most representative member of this family. It is a natural polymer that formed by various chains of bacteria. It is produced from low-cost, renewable feedstock and without causing much impact on the environment. It is degraded in anaerobic and aerobic conditions and it doesn't produce any poisonous materials from its degradation. Copolymer of hydroxybutyrate (PHB) and hydroxyvalerate (HV) is known as poly(3-hydroxybutyrate)- hydroxyvalerate (PHBV). It is a highly crystalline polymer. By increasing the HV unit content, the melting point, the glass transition temperature, the crystallinity and the tensile strength decrease but the impact strength increases. The copolymer PHBV is less brittle than PHB. The degradation rate of PHBV is higher than PHB.

Synthetic biodegradable polymers

Synthetic biodegradable polymers are produced by conventional polymerization procedures such as aliphatic polyesters, polylactide, aliphatic copolymer. Due to the appropriate degradation time and their production in industrial scale, the degradable polyesters are considered as the most potential materials utilized comparing to conventional plastics. They are produced in several forms such as polylactic acid, polycaprolactone and polybutylene succinate. They have low ecological contamination. More than 90% of the biopolymers are polyester as they contain easily hydrolyzable bonds of esters. Synthetic biodegradable polymers may be categorized into bio-based polymers like PLA and oil-based monomers such as PCL.

Aliphatic polyester synthesized from bio-derived monomers (water- based monomers)

The most significant biodegradable polymer is polylactic acid (PLA). It is well-known for being biodegradable and biocompatible polymer. It is synthesized from renewable materials such as potato starch, wheat, rice bran corn and biomass. Polylactic acid is linear aliphatic polyester thermoplastic polymers. Polycondensation and ring-opening polymerization of lactic acid monomers are two processes that may be used to synthesize PLA. PLA's high molecular weight is achieved by polymerization of ring- opening. The final properties of the polymer can be controlled using this method.
Lactic acid monomer exists in three diastereoisomeric structures which are D-lactide, L-lactide, and meso-lactide (DL-lactide). Mechanical, thermal and biodegradable properties of PLA dependen on the selection of stereoisomers distribution within the polymer chain. PLA is used in many applications such as interference screws, sutures, dental, ligating clips, bone pins and rods.

Polyglycolic acid (PGA) is a linear aliphatic polyester that is synthesized by polymerization of ring-opening of cyclic glycolide monomers. It is a thermoplastic and biodegradable polymer. The degradation process of this polymer takes place in two stages. In the first one, water is dispersed in the amorphous regions of the polymer matrix where the ester bonds are separated. In the second stage, crystalline segment of the polymer gets vulnerable to hydrolytic attack. This polymer is used in several applications such as tissue engineering, medical devices, and drug delivery. Glycolic acid monomers (GA) are copolymerized with L-lactide and LD-lactide (LA) generating poly(lactide-co-glycolide) (PLGA). The rate of degradation decreases when the L/G proportion increased. Mechanical and chemical properties are controlled by adjusting the ratio of monomers in the combined polymerization of the PLA and PGA without affecting the compatibility and biodegradability. The degradation of the PLGA takes place by hydrolysis of the ester bond and to form LA and GA which are eco-friendly materials.

Aliphatic polyester synthesized from synthetic monomers (petroleum-based monomers)

Polycaprolactone (PCL) is a biodegradable synthetic linear aliphatic polyester. It can be synthesized by polymerization of ring-opening of caprolactone monomers within the sight of metal alkoxides catalysts. Aluminum isopropoxide and tin octoate are common catalysts used in polymerization process. Polycaprolactone is dissolved in numerous solvents such as methylene chloride. The melting point of PCL is between

58-60 °C. It is degraded by the activity of anaerobic and aerobic microorganisms. The degradation rate of PCL depends on the level of crystallinity and its molecular weight This polymer is used in medical fields such as tissue engineering, long-term drug and vaccine delivery vehicles The biodegradability of PCL can be improved by copolymerization with aliphatic polyesters. PLA and PGA copolymer has lower crystallinity and melting point compared with the homopolymer.

Polybutylene succinate (PBS) can be prepared by polycondensation of 1,4 butanediol with aliphatic dicarboxylic acid succinic acid It is a thermoplastic aliphatic polyester that has a melting point between 90–120 °C. It is decomposed by a hydrolysis mechanism Because PBS is crystalline materials, it degrades slowly. It is normally blended with different materials such as adipate copolymer which acquiring polybutylene succinate adipate (PBSA). This copolymer has a higher degradation rate than PBS.

From a medical point of view, materials based on natural polymers have many beneficial properties, such as biocompatibility, good availability and biodegradability, which is the ability to be degraded in biological systems by the hydrolysis of bonds along the polymer chain followed by oxidation. Therefore, many natural polymers can be decomposed to carbon dioxide, methane, water and biomass by microorganisms or through other biological processes, dependent on several factors, i.e., polymer structure, polymer morphology and molecular weight Another reason to consider natural polymers is the low cost of obtaining and producing them. For these reasons, they have attracted the attention of many research groups. The biocompatibility and functional properties of polymers for oral applications are among the most important clinical issues. When choosing a polymer, one should consider its safety for all oral tissues—gums, mucosa, pulp and bone—additionally eliminating the risk of leaching or the diffusion of toxic

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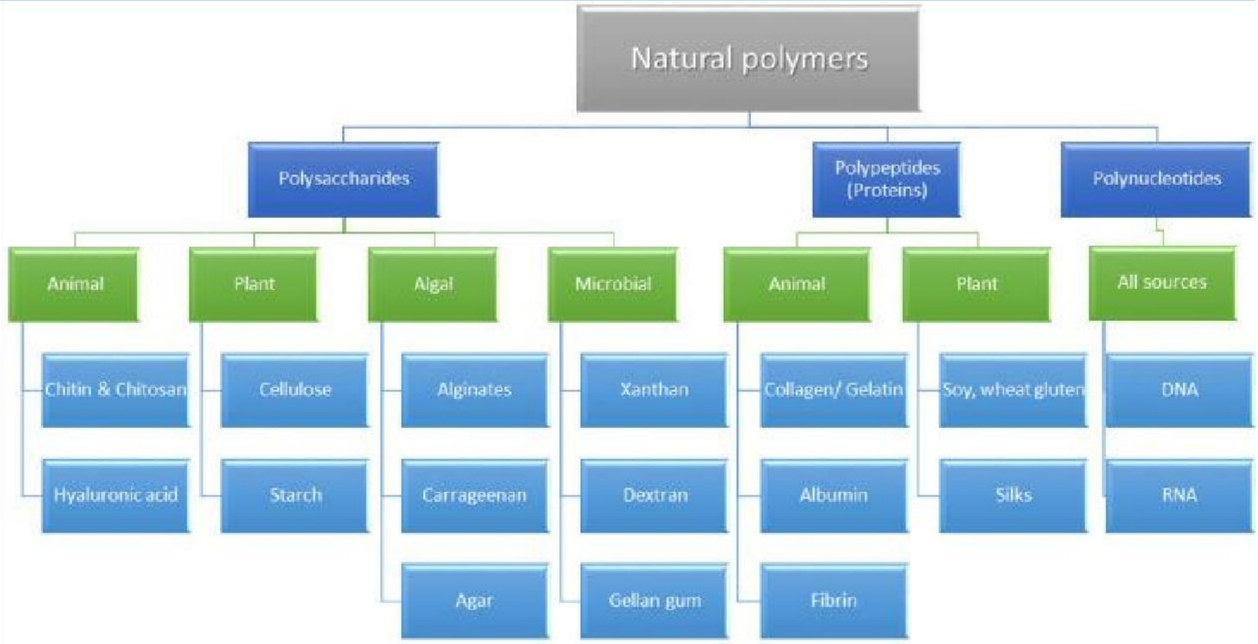
components from materials. Such diffused components could be subsequently absorbed into the body, causing systemic reactions, including toxicity, tissue damage, teratogenic or carcinogenic effects, as well as inducing allergic reactions. Additionally, the effect of dental polymers on blood vessels should also be taken into consideration because the oral cavity is highly vascularized. Several reports from experimental studies provided evidence of a pronounced vasodilator effect of dental polymers that impair pulp healing by promoting hemorrhage.

CHEMICAL CLASSIFICATION AND BIOLOGICAL ACTIVITY OF NATURAL DENTAL POLYMERS



POLYMER DEGRADATION

Polymer corruption is an adjustment in the properties – elasticity, shading, shape, and so forth of a polymer or polymer-based item affected by one or more natural components, for example, warmth, light or chemicals . The term "biodegradation" is restricted to the portrayal of concoction procedures (compound changes that adjust either the atomic weight or solvency of the polymer). 'Bioerosion' might be limited to allude to physical procedures that outcome in weight reduction of a polymer gadget. The bioerosion of polymers is fundamentally of two sorts: Bulk disintegration, Surface disintegration.

Bulk disintegration

- Degradation happens all through the entire of the example.
- Ingress of water is quicker than the rate of corruption

E.g.: polylactic corrosive (PLA), polyglycolic corrosive (PGA).

Surface disintegration

- Sample is dissolved from the surface.
- Mass misfortune is quicker than the entrance of water into the mass. E.g.: polyanhydrides, polyorthoesters.

Grouping of Biodegradable Polymers Considering the Source

Synthetic biodegradable polymers

Aliphatic poly(esters): These are set up by ring opening and polymerization of cyclic ester. Aliphatic polyesters include:

Poly (glycolic acid): Polyglycolide or polyglycolic corrosive (PGA) is a biodegradable, thermoplastic polymer and the least difficult straight, aliphatic polyester.

- It is an intense fiber-framing polymer.
- Due to its hydrolytic unsteadiness its utilization has been restricted.
- It has a glass move hoisted level of temperature between 35°C to 40°C., crystallinity, around 45.
- Its dissolving point is in the reach 55%, along these lines bringing about of 225°C to 230°C. insolubility in water.
- polyglycolide is debased by hydrolysis and separated by specific chemicals.
- Applications: Used to convey drugs as microspheres, inserts and etc.,
- Case of medications conveyed incorporate steroid hormones, anti-microbials, against malignancy operators and etc.,

Polylactic acid: Polylactic corrosive or polylactide (PLA) is a thermoplastic aliphatic polyester got from renewable assets, for example, corn starch, custard items (roots, chips or starch) or sugarcane.

- It can biodegrade under specific conditions, for example, the nearness of oxygen, and is hard to reuse.
- Highly crystalline, high dissolving point, low dissolvability.
- Bacterial aging is utilized to create lactic corrosive from corn starch or natural sweetener.
- Applications: PLA is utilized as a part of the readiness of sutures or orthopedic gadgets.

Polycaprolactone: Polycaprolactone (PCL) is a biodegradable polyester.

- It has a low liquefying purpose of around 60°C.
- It has a glass move temperature of about -60°C.
- Slower corruption rate than PLA.
- It stays dynamic the length of a year for medication conveyance.
- Applications: Drug conveyance utilizations of PCL incorporates: Cyclosporin as nanoparticles, Ciprofloxacin as dental inserts.

Factors Affecting Biodegradation of Polymers

Morphological factors

- Shape and size
- Variation of dissemination coefficient and mechanical hassles

Chemical factors

- Chemical structure and organization
- Presence of ionic gathering and setup structure
- Molecular weight and nearness of low sub-atomic weight mixes

Physical factors

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- Processing condition
- Sterilization process

Advantages of biodegradable polymers

- Localized conveyance of medication
- Sustained conveyance of medication
- Stabilization of medication
- Decrease in dosing recurrence
- Reduce symptoms
- Improved persistent consistence
- Controllable debasement rate

Applications of biodegradable polymers

- Polymer framework for quality treatment.
- Biodegradable polymer for visual, tissue building, vascular, orthopedic, skin glue and surgical pastes.
- Biodegradable medication framework for helpful specialists, for example, against tumor, antipsychotic operator, mitigating operator
- Polymeric materials are utilized as a part of and on soil to enhance air circulation, and advance plant development and wellbeing.
- Many biomaterials, particularly heart valve substitutions and veins, are made of polymers like Dacron, Teflon and polyurethane.

USE OF BIODEGRADABLE POLYMERS IN THE MEDICAL FEILD

The application of non-degradable materials for medical use is currently very limited, for example, shunts for a brain edema, intraocular lenses, artificial blood vessels, wound covering patches, dental implants, orthopedic implants, such as artificial joints, and implants for plastic surgery, such as breast saline bags. The reasons for this narrow usage are poor biological functions and insufficient biocompatibility, which are required for ideal biomaterials . In contrast, the utilization of biodegradable materials is an attractive method for the following two reasons. Firstly, because the use of sutures or prostheses becomes needless after the defected site is repaired. The recent development of drugs and reparative medicine accelerate this tendency. Secondly, because the requirements for safety and biocompatibility are considered to become severe in the future. Although the current non-degradable synthetic materials are well investigated and proved to have low toxicity, few of them have suitable biocompatibility, because there is often an immune-rejection against or an encapsulation of the long-lasting non- degradable foreign substances in vivo. In contrast, since biodegradable materials are finally absorbed and disappear, the long-term biocompatibility is not required, though the toxicity of degraded substances has to be carefully controlled.

Poly Lactic acid, Poly Crypolactone, Chitosen etc. Among all these Poly (lactic acid) (PLA) is the most readily biodegradable polymer in the surgical field. The biodegradable polymers have gained growing importance in the medical area, and these have been used in a wide number of applications in the human body, such as surgical sutures, controlled drug release systems, artificial skins, guides for nerves, veins and artificial arteries and orthopaedic devices

Chitosan is a cationic polysaccharide that has been examined in an adjuvant setting due to its biocompatible and biodegradable nature. The polysaccharide has been shown to have the capacity to induce Th1 cell responses following vaccination by injection or mucosal routes, supporting its application as an alternative to alum for vaccines that promote cell-mediated immunity.

Zein, a plant-derived protein, is a promising and environmentally friendly material for drug delivery. Zein-based carriers have been explored for anticancer drugs through various administration routes, including intravenous injection, oral administration, transdermal absorption, intratumoral injection, and pulmonary inhalation. Zein has multiple methods for drug loading, such as hydrophobic interaction, chemical conjugation, deposition, and electrostatic interaction, but hydrophobic interaction has been more commonly studied for the insoluble small molecules in current anticancer drugs. Currently, nanoparticles loaded with antitumor drugs are the main type of zein-based carriers used for intravenous injection and oral administration. With the development of micro/nanotechnology, zein-based nanofibers, microneedles, and hydrogels have been explored for controlled release and more effective local treatment. Among the various administration routes, the oral route is particularly advantageous due to zein's good hydrophobicity and resistance to the gastrointestinal environment. Moreover, functionalization of zein-based carriers is crucial in drug delivery, including enhancing targeting and stimulating responsive release. Zein has free amino and hydroxyl groups, which make it easily modifiable and have the potential to be developed as a functional drug carrier.

The use of biodegradable polymers for treating bone-related diseases has become a focal point in the field of biomedicine. Recent advancements in material technology have expanded the range of materials suitable for orthopaedic implants. 3D printing is capable of creating 3D structures that are supportive and controllable. The technique has shown promise in fields such as tissue engineering and regenerative medicine, and new innovations in cell and bio-printing and printing materials have expanded its possibilities. In clinical settings, 3D printing of biodegradable metals is mainly used in orthopedics and stomatology. 3D-printed patient-specific osteotomy instruments, orthopedic implants, and dental implants have been approved by the US FDA for clinical use. There has been increasing interest in biodegradable metals such as magnesium, calcium, zinc, and iron. The advantages of 3D printing, such as low manufacturing costs, complex geometry capabilities, and short fabrication periods, have led to widespread adoption in academia and industry.

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