Introduction

Polymers are long-chains molecules that are formed by connecting large numbers of repeating units (monomers) by covalent bonds. Polymers form the largest category of diverse biomaterials. Based on their source of origin, they can be categorized as synthetic (e.g. polyethylene) or natural type (e.g. collagen). Synthetic polymers can be further sub-divided into biodegradable and non-degradable types. In the degradable type, the polymer is broken down in vivo due to hydrolytic and enzymatic degradation. The resultant nontoxic compounds include lactic and glycolic acid, respectively. One of the key issues while considering polymers for bio applications is their biocompatibility with the host tissue and their degradation characteristics over extended periods of time. Biopolymer applications range from drug release carriers, implants, tissue regeneration scaffolds to sutures.

Polymeric biomaterials are chosen for different applications depending on their properties and are widely used in clinical applications such as dentistry, ophthalmology, orthopedics, cardiology, drug delivery, sutures, plastic and reconstructive surgery, extracorporeal devices, encapsulates and tissue engineering.

Polymer and environment

A world without plastics, or synthetic organic polymers, seems unimaginable today, yet their large-scale production and use only dates back to ~1950. Although the first synthetic plastics, such as Bakelite, appeared in the early 20th century, widespread use of plastics outside of the military did not occur until after World War II. The ensuing rapid growth in plastics production is extraordinary, surpassing most other man-made materials. Notable exceptions are materials that are used extensively in the construction sector, such as steel and cement.

The traditional polymer materials available today, especially the plastics, are the result of decades of evolution. Their production is extremely efficient in terms of utilization of raw materials and energy, as well as of waste release. The products present a series of excellent properties such as impermeability to water and microorganisms, high mechanical strength, low density (useful for transporting goods), and low cost due to manufacturing scale and process optimization .

Before we use materials that can accumulate in nature, we must think about reducing their consumption, reusing and recycling (either by reuse of raw materials, or by use of the energy of combustion). However, certain parts that are formed by small amounts of polymer (ie, a few grams) and may still be contaminated by food are difficult to be collected from nature, cleaned, sorted and recycled, both from the economic and also from the environmental (energy consumption and soil pollution of the process) point of view. This is the case of plastic bags and packaging, especially plastics used in food, in medical and hygiene. In these cases, the use of biodegradable polymer materials may be an excellent solution to the environment .

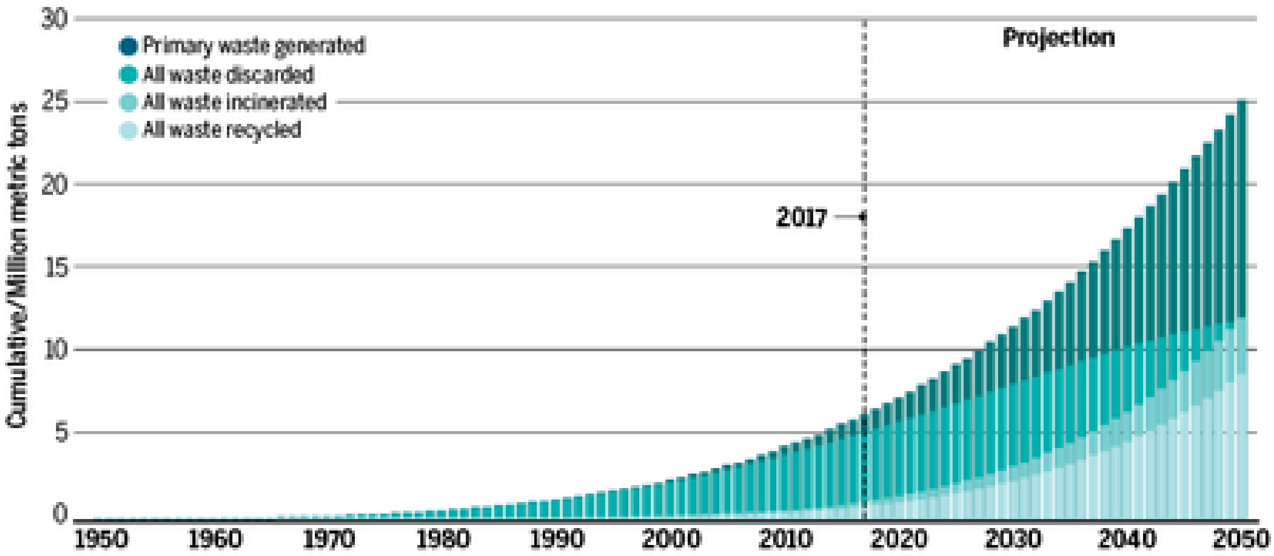
During the 1960s percipient environmentalists became aware that the increase in volume of synthetic polymers, particularly in the form of one-trip packaging, presented a potential threat to the environment, what became evident in the appearance of plastics packaging litter in the streets, in the countryside and in the seas .

PLASTIC pollution in oceans is a growing problem. Over time, movement of waves and exposure to the sun breaks the material into tiny particles called microplastics which harm even the smallest oceanic organisms. Two studies published in the journal Current Biology on examined the effects of microplastics on lugworms, which are a source of food for fish and birds and play an important role in nutrient recycling.

One of the studies found that lugworms are up to 50 per cent less energetic if ocean sediments contain significant amounts of microplastics. This had a serious effect on their growth and reproduction.

By 2050, we'll have produced 26 billion tons of plastic waste

Historical data and projections to 2050 of plastic waste production and disposal. "Primary waste" is plastic becoming waste for the first time and doesn't include waste from plastic that has been recycled.



Classification Based on Molecular Forces:

The mechanical properties of polymers are governed by intermolecular forces, e.g., van der Waals forces and hydrogen bonds, present in the polymer, these forces also bind the polymer chains Under this category, the polymers are classified into the following groups on the basis of magnitude magnitude of intermolecular inter molecular forces present present in them, they are :

(i) Elastomers (ii) Fibers (iii) Liquid resins (iv) Plastics [(a) Thermoplastic and (b) thermosetting plastic.

Elastomers: These are rubber – like solids with elastic properties. In these elastomeric polymers, the polymer chains are random coiled structure, they are held together by the weakest intermolecular forces , so they are highly amorphous polymers. A few 'crosslinks' are introduced in between the chains, which help the polymer to retract to its original position after the force is released as in vulcanised rubber such as neoprene .

Fibers: If drawn into long filament like material whose length is at least 100 times its diameter, polymers are said to have been converted into 'fibre'

Fibres are the thread forming solids which possess high tensile strength and high modulus , Examples are polyamides (nylon 6), polyesters .. etc.

Liquid Resins: Polymers used as adhesives, potting compound sealants, etc. in a liquid form are described liquid resins, examples are epoxy adhesives

Plastics: A polymer is shaped into hard and tough

Typical examples are polystyrene, PVC and polymethyl methacrylate. They are two types

(a)Thermoplastic and (b)Thermosetting plastic.

Advantages of biopolymers

- Not expensive.
- Easy to fabricate.
- Resistance to corrosion.
- Wide range of physical, chemical and mechanical properties.
- Low density (low weight).
- May be biodegradable.
- Good biocompatibility.
- Low coefficients of friction.

Disadvantages of Polymers

- Low mechanical strength.
- Thermo sensitive.
- Easily degradable.
- Absorb water & proteins etc.
- Wear & breakdown.
- Sensitive to sterilization techniques because of their permeability and porous structures.
- Bacterial colonization because of their organic structure.

In orthopedic applications (screws…)

- Metal alloys present greatest load bearing.
- Polymers present lower load bearing.

In vascular applications (stents…)

- Magnesium alloys degrade too fast in biological environment and they dissolve in the body.
- Polymers degrade slower than magnesium alloys.

Biodegradable Polymers

Biodegradable polymers are designed as temporary structures having the desired geometry and the physical, chemical, and mechanical properties required for implantation.

Biodegradable polymeric biomaterials have been experimented with as (1) vascular grafts (2) vascular stents, (3) nerve growth conduits, (4) defected bone, (5) ligament/tendon prostheses.

Mechanisms causing degradation

Physical

- sorption/swelling,
- softening,
- dissolution,
- stress cracking,
- fatigue cracking.

Chemical

- hydrolysis,
- oxidation
- enzymatic

Polymers used as biomaterials

Although hundreds of polymers are easily synthesized and could be used as biomaterials only ten to twenty polymers are mainly used in fabrication of medical device from disposable to long-term implants.

1-Polyvinylchloride (PVC)

PVC is used mainly as tubing and blood storage bags in biomedical applications. Typical tubing uses include blood transfusion, feeding, and dialysis. Pure PVC is a hard, brittle material, but with the addition of plasticizers, it can be made flexible and soft. PVC can pose problems for long-term applications because the plasticizers can be extracted by the body. While these plasticizers have low toxicities, their loss also makes the PVC less flexible.

2- Polyethylene (PE)

HDPE is used in pharmaceutical bottles.

LDPE is used for flexible container applications, disposable for packaging.

LLDPE(linear low density) is employed in bags due to its excellent puncture resistance.

UHMWPE(**Ultra-high-molecular-weight polyethylene)**Also known as **high-modulus polyethylene**, (**HMPE**), or **high-performance polyethylene** (**HPPE**), has been used for fabrication of orthopedic implant, especially for load bearing applications such as an acetabular cup of total hip and the surfaces of patellar of knee joints.

3- Polytetrafluroethylene (PTFE,) also known as PTFE Teflon, has the same structure as PE, except that the four hydrogens in the repeat unit of PE are replaced by fluorines. PTFE is a very high melting polymer (Tm = 327◦C) and as a result it is very difficult to process. It is very hydrophobic, has excellent lubricity, and is used to make catheters. In microporous form, known generically as e-PTFE or most commonly as the commercial product Gore-Tex, it is used in vascular grafts. Because of its low friction, it was the original choice by Dr. John Charnley for the acetabular component of the first hip joint prosthesis, but it failed because of its low wear resistance and the resultant inflammation caused by the PTFE wear particles.

4- Polypropylene (PP)

This is a very simple polymer whose structure is almost similar to PE. It's mechanical properties are also balanced. The one thing that sets this one apart is the hing property that it has.PP is used to make disposable syringes, packaging for devices, solutions, drugs, suture, and artificial vascular grafts, etc.

PP is an isotactic crystalline polymer with high rigidity, good chemical resistance, and good tensile strength. Its stress cracking resistance is excellent.

5- Polymethylmetacrylate (PMMA)

PMMA is a hydrophobic, linear chain polymer that is transparent, amorphous, and glassy at room temperature and may be more easily recognized by such trade names as Lucite or Plexiglas. It is a major ingredient in bone cement for orthopedic implants. In addition to toughness and stability, it has excellent light transmittance, making it a good material for intraocular lenses (IOLs) and hard contact lenses. The monomers are polymerized in the shape of a rod from which buttons are cut. The button or disk is then mounted on a lathe, and the posterior and anterior surfaces machined to produce a lens with defined optical power. Lenses can also be fabricated by melt processing, compression molding, or casting, but lathe machining methods are most commonly used.

Soft contact lenses are made from the same methacrylate family of polymers. The substitution of the methyl ester group in methylmethacrylate with a hydroxyethyl group (2-hydroxyethyl methacrylate or HEMA) produces a very hydrophilic polymer. For soft contact lenses, the poly(HEMA) is slightly cross-linked with ethylene glycol dimethyacrylate (EGDMA) to retain dimensional stability for its use as a lens.

Fully hydrated, it is a swollen hydrogel. PHEMA is glassy when dried, and therefore, soft lenses are manufactured in the same way as hard lenses; however, for the soft lens a swelling factor must be included when defining the optical specifications.

PMMA is used broadly in medical applications such as a blood pump and reservoir, membranes for blood dialyzer, and in vitro diagnostics. It is also found in contact lenses and implantable ocular lenses due to excellent optical properties, dentures, and maxillofacial prostheses due to good physical and coloring properties, and bone cement for joint prostheses fixation.

Bone cement: Mixture of polymethylmethacrylate powder and methylmethacrylate monomer liquid to be used as a grouting material for the fixation of orthopedic Joint implants.

6- Polystyrene (PS)

PS is commonly used in roller bottles.

7- Polyurethanes

Polyurethanes are tough elastomers with good fatigue and blood-containing properties. They are used in pacemaker lead insulation, catheters, vascular grafts, heart assist balloon pumps, artificial heart bladders, and wound dressings.

8- polycarbonates

Polycarbonates have found their applications in the heart/lung assist devices, food packaging**.**

9- Polyethylene terephthalate, called Dacron,

Is used in the artificial heart valves. Dacron is used because tissue will grow through a polymer mesh. Dacron is used for large arteries.

In general the biopolymer may be:

Thermoplastic biopolymer: materials that can be shaped more than once. (Used as replacements for blood vessels.).

Thermosetting biopolymer: materials that can only be shaped once (Used in dental devices, and orthopedics such as hip replacements.).

Elastomer biopolymer: material that is elastic. If moderately deformed, the elastomer will return to its original shape. Used as catheters.

10-Hydrogels

Hydrogel is a colloidal gel in which water is the medium of dispersion and is formed by the cross-linking network of hydrophilic polymer chains.

Hydrogels are a three-dimensional network of hydrophilic polymers held together by association bonds such as covalent bonds and weaker cohesive forces such as hydrogen and ionic bonds and intermolecular hydrophobic association.

These networks are able to retain a large quantity of water within their structure without dissolving. Due to their superior chemical and physical properties, hydrogels have received much attention for preparing biomedical materials.
The elastic nature of the hydrated hydrogels when used as implants has been found to minimize irritation to surrounding tissue. The low interfacial tension between the hydrogel surface and the aqueous solution has been found to minimize protein adsorption and cell adhesion.

Table (1) Classification of Hydrogels

Classification	Contents
Source	Natural Synthetic
Component	Homopolymer Copolymer Multipolymer
Preparation method	Simultaneous polymerization Crosslink of polymer
Electric charge	Nonion Anion Cation Zwitter ion
Physical structure	Amorphous Semicrystaline Hydrogen bonded
Crosslink	Covalent bond Intermolecular force
Functions	Biodegradable Stimuli responsive Superabsorbent Etc.

Hydrogels
containing more than 95% of water of the total weight (or volume) of the hydrogel are called superabsorbent. Hydrogels can maintain their shape due to the isotropic swelling.

MEDICAL APPLICATIONS OF HYDROGELS

Because of their extraordinary biocompatibility, hydrogels have been successfully used in a wide range of biomedical applications that include lubrication for surgical gloves, urinary catheters and surgical drainage systems, contact lenses, wound dressings, and drug delivery systems.

A. Lubricant

Hydrogels have been used extensively for lubricating the surfaces of biomaterials. As the dry surface of latex gloves and catheters exhibits a high faction coefficient, hydrogels were applied to provide a low friction surface. Similarly, drainage tubes used to evacuate collections of fluid within body cavities require surface lubricity to facilitate insertion and removal.

The mechanical friction between a catheter and the mucosa tissue may injure the urethra and may cause micro hematuria Because of this side effect, hydrogel coatings have been applied to catheters to protect the urethra and form a hydrophilic lubricious surface.

B-Contact Lens

Contact lenses are used to correct the optical function of the eye with intimate contact to the eye . Contact lenses are classified into two groups: soft (flexible) and hard contact lenses. Hydrogel contact lenses are a member of soft contact lens group. The hydrogel lenses are made of slightly crosslinked hydrophilic polymers and copolymers.

The original material for hydrogel contact lens was poly(2-hydroxyethyl methacrylate) (polyHEMA) **,** Hydrogel contact lenses are more comfortable than other types and are easier to fit.

C. Dressing

Historically, gauze or nonwovens of cotton or wool have been used in medicine for a long time. Nowadays, there exist a plenty of polymeric wound covering materials.

They are subdivided into polymer films, polymer foams, hydrogels, hydrocolloids, and alginates. The prerequisites for a successful wound covering material are flexibility, strength, non-antigenicity, and permeability of water and metabolites . As a barrier effect, a secure wound covering is also necessary to prevent infection **.**

In one method, a hydrogel monomer is mixed with drug, initiator, and crosslinked and is polymerized to entrap the drug within the matrix.

D. Tissue Engineering

Tissue engineering has been extensively studied by many researchers in a wide area. Tissue engineering, as well as cell transplantation, has been the most widely investigated strategy in the recent biomaterials field. Tissue engineering aims at restoring a tissue defect by inducing endogenous tissue regeneration and manipulating the cascades of cellular events during the healing process. Tissue engineering uses polymer devices with controlled macro- and microstructures and chemical properties to achieve organ regeneration. Combination of cells and an immunoisolative membrane forms bio hybrid organs, which become a permanent part of the host organ by acting as the functional analog of the original organ by continuously supporting the organ.

11- Silicone elastomers

Silicone elastomers have a long history of use in the medical field.

They have been applied to cannulas, catheters, drainage tubes, balloon catheters, finger and toe joints, pacemaker lead wire insulation, components of artificial heart valves, intraocular lenses, contraceptive devices, burn dressings and a variety of associated medical devices.

12- Natural rubber

Natural rubber is strong and one of the most flexible of the elastomers. The material has been used for surgeon's gloves, catheters, urinary drains. However, because it has the potential to cause allergic reactions thought to be due to the elution of entrapped natural protein, this elastomer is being used less now than in the past.

13- Biological Polymers

Biopolymers are natural materials such as carbohydrates, proteins, cellulose, DNA and RNA that produced by living organisms.

Carbohydrates.

Proteins are big molecules present in living cells (animal tissues, skin, nails, muscles).*Proteins are polyamides*

Cellulose :
Cellulose, which is obtained from processed cotton or wood pulp, is one of the most common fiber-forming biopolymers. Because of the highly absorbent nature of cellulose fibers, they are commonly used in feminine hygiene products, diapers, and other absorbable applications, but typically are not used *in vivo* because of the highly inflammatory reactions associated with these materials.

DNA- Deoxyribonucleic Acids.

RNA - Ribonucleic Acids.

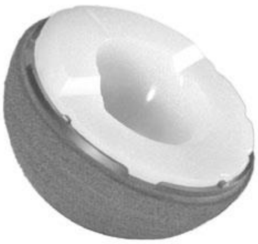
DNA & RNA are polyesters (of H_3PO_4*).*

Polymers in Specific Applications

Application	**Properties and design requirements**	**Polymers used**
Dental	• Stability and corrosion resistance. • Strength and fatigue resistance. • Good adhesion/integration with tissue. • Low allergenicity.	PMMA polyamides
Ophthalmic	• gel or film forming ability • oxygen permeability	polyacrylamide PHEMA (polyhydroxyethylmethacrylate)
Orthopedic	• Strength and fatigue resistance. • good integration with bones and muscles	PE, PMMA
Cardiovascular	• fatigue resistance, lubricity, • sterilizability	silicones, Teflon, poly(urethanes)
Drug delivery	• compatibility with drug, biodegradability	silicones, HEMA
Sutures	• good tensile strength, strength retention • flexibility, knot retention.	PP, nylon

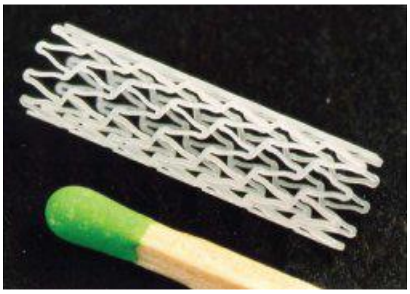
Some examples of polymeric biomaterials:

acetabular cup of hip joint



Spinal cage for spine fusion

Vascular Implants & Stents



Cartilage

Artificial heart valve