Synthesis and Characterization of Polymer Based Materials for Biomedical Applications

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Abstract: This study summarizes the many biomedical and biomechanical applications of polymer-based materials. The use of polymer-based materials in medical implants and equipment allows for the restoration or enhancement of function of damaged or disconnected tissues or organs, thereby benefiting patients. Appropriateness to the body is the most important factor to consider while choosing the biomaterial. For materials made of polymers to be useful over the long haul, they need to meet certain criteria. Polymers with shape memory and shape-changing capabilities are examples of this class of materials that can perform active movements triggered by external inputs. In the recent two decades, these materials have garnered a lot of attention in the biomedical field, particularly for use in minimally invasive procedures. This is why polymeric biomaterials have been and will continue to be crucial to the development of innovative antibacterial technologies for use in biologic applications. Topics covered in this study include biomolecule conjugates of smart polymers on surfaces, various forms of smart polymeric biomaterials, and the characteristics and applications of smart polymers. This page provides a synopsis of the three main categories of polymeric-based materials, outlining their respective areas of use.

Keywords: Biomedical, Biomaterial, Gel, Biomedical, Polymer, Biomechanics, Tissue

1. INTRODUCTION

Biomaterials are defined most recently by the American National Institutes of Health as "any substance or combination of substances, other than drugs, synthetic or natural in origin, which can be used for any period of time, augmenting or replacing partially or totally any tissue, organ, or function of the body in order to maintain or improve the quality of life of the individual." This definition applies to both synthetic and natural substance options. There are three main categories into which biomaterials fall: polymeric, metallic, and ceramic. Newer hybrid biomaterials may be created by synthesizing combinations of biomaterials within or across classes. For a substance to be eligible for the biomaterial classification, biocompatibility is an essential quality. For a substance to be considered biocompatible, it must not only be non-toxic but also able to elicit the desired reaction from the host organism in a given setting. Materials' biodegradability and bio functionality for a certain application, however, are more comprehensive criteria. Stainless steel (316L)[1][2], cobalt-chromium (Co-Cr) alloys, titanium (Ti-6Al-4V), amalgam (AgSnCuZnHg), nickel-titanium (Ni-Ti), and other metals and alloys are examples of metallic biomaterials. Metals provide several benefits when used as biomaterials, including increased strength, resistance to fatigue and wear, ease of production and sterilizing, shape memory capabilities, and many more. On the other hand, there are a few drawbacks, such a high

modulus, corrosion, susceptibility to and toxicity from metal ions[3], a metallic appearance, and so on. Biomaterials derived from ceramics include apatite, silicate glass, alumina, partly stabilized zirconia, calcium carbonate, and others. Despite their brittle nature and manufacturing problems, ceramics have several benefits, such as high compression strength, resistance to wear and corrosion, a highly polished surface, and bioactivity or inertness. Fracture and corrosion are detrimental in the long run. Natural and synthetic polymers are both included in the category of polymer based biomaterials [4]. The processing, modification, and functional tuning of the physical and mechanical characteristics of different bodily tissues and organs may be facilitated by the intrinsic flexibility of polymers. One group of biomaterials that has received a lot of attention for its potential medicinal uses is polymers [5]. Biomaterials composed of polymers may be further categorized into two groups: those derived from natural polymers and those derived from synthetic polymers. Benefits of synthetic polymers include the following: biodegradability, biocompatibility, immobilization of cells, simpler production of complex forms, and tailorability of physical and mechanical characteristics [6][7]. On the other hand, they have a number of drawbacks, such as being highly leachable, absorbing water and proteins, being contaminated, wearing down quickly, producing unwanted biodegradable products, and being difficult to sterilize. Biobased biomaterials, which are derived from natural polymers, have several desirable properties, such as being biocompatible, biodegradable, and exhibiting little or no cytotoxicity [8]. Additionally, for certain naturally occurring biopolymers, they exhibit bio mimicking properties and natural bioactivity. The most common uses of biomaterials fall under

a) Tissue engineering scaffolds,
b) Cardiovascular medical devices (stents, grafts and etc.),
c) Orthopedic and dental applications
d) Implants,
e) Ophthalmologic applications (contact lenses, retinal prostheses etc.),
f) Bio-electrodes and biosensors,
g) Burn dressings and skin substitutes,
h) Sutures and
i) Drug delivery systems etc.

Any substance that interacts with biological processes, whether it be natural or manufactured, and frequently made up of numerous pieces, is considered a biomaterial. "Smart" or "stimulus responsive" polymers are long-chain monomers that may quickly and significantly change their phase or properties in response to small changes in physical or chemical parameters near a critical state [1]. These polymers are also known as "smart," "environmentally sensitive," or "responsive" polymers. There are a variety of polymers that might be present; for example, they can be grafted, adsorbed, dissolved in an aqueous-solid environment, or crosslinked to form hydrogels in water-based solutions. They may also be physically or chemically combined with other particles, especially different bioactive compounds [2]. Several evaluations have shed light on smart polymer applications in the biomedical field during the past 20-25 years [3-7]. In addition to the many triggers that have been investigated, researchers have focused on a small number of stimulus-responsive polymers [8]. By triggering the polymer's smart reaction, the next step usually depends on the polymer's initial state. Here are the characterized descriptions[9].

• Once a clever polymer is dissolved in water, turbidity starts to form quickly. If the content is high enough, it can change from a high-viscosity solution to a gel.

• When a polymer is chemically transplanted into a water-solid device, it can disrupt the interface by becoming hydrophobic. Dynamic adsorption at the interface occurs when a solution-dissolved smart polymer is activated in the presence of a solid-aqueous substratum that distinguishes phases. This is especially true when the surface architecture is close to the smart polymer and exhibits an equilibrium between hydrophobic and polar bands. It is possible to chemically link a smart polymer to a network. Being a "thinking hydrogel" means it has swelled to its critical point in solutions. Once the hydrogel's swelling material breaks, the polymer structure may move freely in its critical environment, causing the hydrogel to split and release more. All these consequences are altered when a trigger is flipped. An increase in the system's entropy, brought about by the release of hydrophobically bound water molecules onto the polymer backbone, powers the phase separation of water-solved smart polymer chains [10]. Despite the need to rehydrate the hydrophobic polymer groups in the opposite phase, the reverse acceleration to the

hydrogenated state may be smaller than the breakdown. This strategy is thermodynamically opposed by the ensuing drop in entropy network. Smart polymer system measurements may also depend on the risk of failure and reversal. Smaller systems, such as microscale and nanoscale ones, will have tariffs applied more quickly [11]. A chemical link between a biomolecule and an intelligent polymer may produce a variety of physical, biologic, and chemically reactive polymerbiomolecular "biohybrid" structures[12]. Various intelligent polymer systems, including peptide-protein complexes, polysaccharides-sugars, oligonucleotides (both single-stranded and double-stranded), phospholipids, based lipids, and a variety of identifying ligands and synthesized medicinal atoms, may be combined with these biomolecules [13]. The term "double smart" may describe some of these biohybrids. Connecting the intelligent polymer backbone to polyethylene glycol (PEG), which offers "stability" properties, is another additional option.

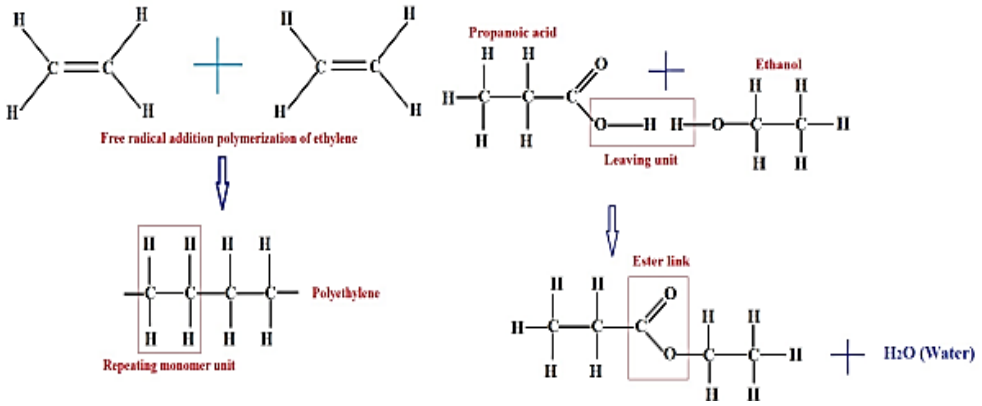

Figure 1. Representation of addition and condensation polymerization processes

2. POLYMER BASED BIOMATERIAL

It is possible to classify polymer-based biomaterials as either synthetic or natural. The scaffolding ability of both synthetic and naturally occurring polymers has been studied. One possible benefit of using naturally occurring polymers for tissue regeneration is their ability to promote cell growth via biological recognition[14]. This is shown in examples of polysaccharides and proteins. One major issue with natural polymers is the inherent variety in their properties. Beyond their inherent unpredictability, proteins also have the unsavory side effect of triggering immune responses. For instance, collagen's surface chemistry is ideal for cell proliferation and differentiation, which has led to its application as a scaffolding material and in tissue regeneration. Collagens, on the other hand, have a history of immunogenicity and pathogen transmission, poor mechanical qualities, biodegradability issues, and handling challenges.[15]

Synthetic polymer based biomaterials:

The biomaterials for tissue engineering that are synthetic polymers have attracted a lot of interest due to their predictable qualities, ease of production for particular applications with optimal features, excellent repeatability, and adaptability in composition[16]. Modifying polymers by chemical, physical, or processing processes may give biological activity and biodegradability, for example. Composite materials are engineered to fulfill the many needs of tissue engineering that individual polymers are unable to, and they also make chemical modification of polymers for desired properties simpler. Most synthetic polymers have a reduced biodegradability, which is a drawback. But there are synthetic polymers, mostly polyesters like polyglycolides and polylactides, that break down in living organisms[17]. Poor biocompatibility, mechanical property loss, and acidic breakdown product release are still issues, however. A variety of synthetic polymers are used in biomaterials. These include hydrophilic materials like PEG, PVA, and PAAM, as well as hydrophobic polymers like poly(n-butyl acrylate) and poly-(α-esters). For controlling microstructure formation, drug delivery, and cell adhesion, thermosensitive polymers like poly(N-isopropylacrylamide) (pNIPAAM) and amphiphilic polymers like (PEG-b-PPO-b-PEG) have been extensively used. Of these polymers, PEG stands out as a biomaterial favorite due to its affordability, low polydispersity index (PDI), ease of end-functionalization, and solubility in various organic solvents[18]. The advantages of functionalizing PEG with small molecule medicines,

peptides, and proteins include longer circulation lifetime, decreased elimination routes, and higher effectiveness. As a result, this method has been extensively used.

Hydrogel based biomaterials

The biomimicking properties of hydrogel have led to its considerable investigation and usage as biomaterials. With the ability to absorb huge amounts of water and be engineered to match the chemical and mechanical characteristics of real tissue environments, hydrogels are three-dimensional macromolecular networks that are cross-linked by physical or chemical interactions. They are the most lifelike synthetic biomaterials because of their high water content, porosity, and supple texture, which mimic the characteristics of real biological tissue[19].

Hydrogels may either be chemically stable or undergo degradation, breaking down and dissolving over time. A vast array of chemical compositions and bulk physical characteristics may be shown by hydrogels, which are composed of various water-soluble polymers. One of the many physical forms that hydrogels can take is a slab, but they also come in microparticles, nanoparticles, coatings, and films. These forms allow hydrogels to be used in diagnostics, cellular immobilization, separation of biomolecules or cells, barrier materials to regulate biological adhesions, and tissue engineering and regenerative medicine, among many others.

There has been a plethora of research on hydrogel structure control because of the many opportunities it presents for meeting specific demands in niche industries. It is common practice to modify hydrogels with cellular adhesion domains for use in soft tissue regeneration and pharmaceuticals for controlled release [20]. Hard tissue engineering has also made use of thick polymeric materials, such as dried stiff scaffolds. Molecular entanglements are formed in the "physical" or "reversible" gel by secondary interactions including ionic, H-bonding, or hydrophobic forces, leading to the creation of a network.

Environmental factors including pH, ionic strength of solution, and temperature may dissolve physical gels, and the process is reversible. The creation of a network in a "permanent" or "chemical" gel occurs via covalent connections; the presence or absence of charges in these gels is determined by the functional groups included in the polymeric network. It is known that charged hydrogels may change form when exposed to an electric field, and they often show changes in swelling when the pH is changed[12]. There are two main methods for creating chemical hydrogels: either by directly cross-linking water-soluble polymers or by "three-dimensional polymerization," which involves polymerizing a hydrophilic monomer with a polyfunctional cross-linking agent.

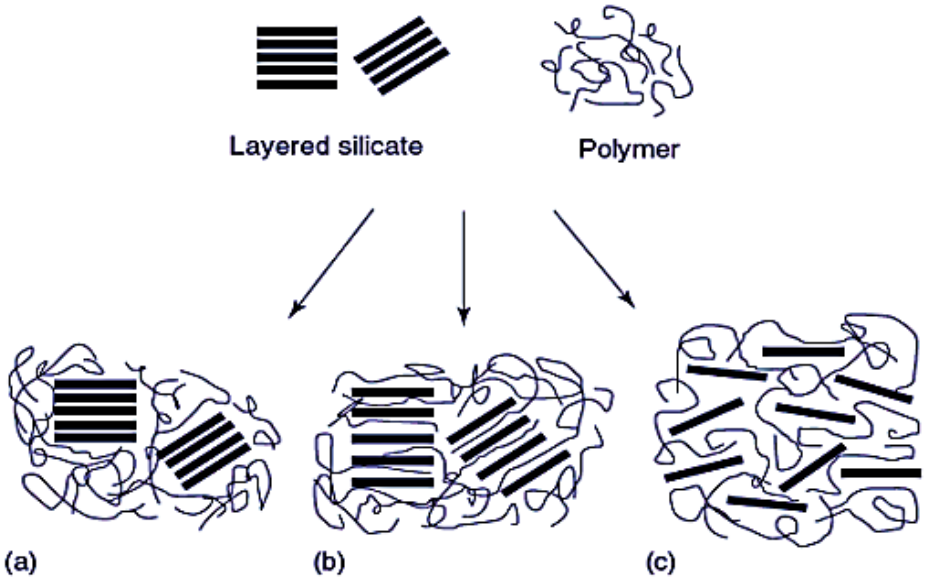

Figure 2 Types of composite microstructures: (a) Unintercalated (Phase separated (microcomposite)), (b) intercalated (Intercalated (nanocomposite)), and (c) exfoliated (nanocomposite).

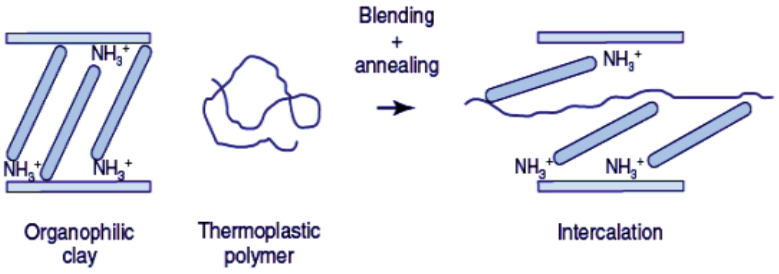

Fig. 3 Melt intercalation process

Hydrogels in drug delivery

Research into hydrogels for drug administration has been piqued due to their unique swelling response to aquatic environments. By manipulating the hydrogel's affinity for the water and the density of its crosslinks, it's extremely porous network structure may be readily altered. The porosity of these gels makes it easy to load them with medications, and then they release those drugs at a pace that matches the small molecule's or macromolecule's diffusion coefficient via the network of holes in the gel[13]. One possible pharmacokinetic advantage of hydrogels for drug administration is the creation of a release depot from which the pharmaceuticals elute slowly. This allows the medication to retain a higher local concentration at the intended spot than in the surrounding tissues for a long time. Hydrogels were also used in systemic delivery and sustained release devices. Hydrogels are appropriate for in-vivo application because of their high water intake capacity, they are typically quite biocompatible, and their physiochemistry is comparable to that of natural extracellular matrix. However, depending on the time scale and location of the drug delivery device, degradation may not always be desired. Hydrogels may be constructed with biodegradability or dissolution in mind using enzymatic, hydrolytic, or environmental (e.g., pH, temperature, or electric field) routes[14].

Hydrogels in tissue engineering

Although medical prostheses and transplants are options, they fall short of replacing a person's natural, undamaged physiological state, which is why regenerative medicine shows great promise as a way to improve healthcare quality. That is why regenerative medicine experts are always trying new things in their quest to find better medical solutions. Hence, it is crucial to choose physical components or materials for tissue engineering that are both intrinsically safe and more akin to real tissues[15]. Hydrogels are intriguing as a potential material for tissue scaffolds or medicinal delivery systems because of their similarities to the extracellular matrix and their ability to support cell proliferation and survival. As a material with acceptable physical properties, hydrogels are ideal for use in regenerative medicine due to their unique biocompatibility, adaptable manufacturing processes, and wide variety of ingredients. As a scaffold, hydrogels provide structural support and volume for cellular organization and morphogenesis; they also function as bio-adhesives and tissue barriers; they work as drug depots; and they supply bioactive compounds for neotissue constructions. Hydrogels have a long history of usage in regenerative medicine. Over the last several decades, a plethora of hydrogel types have been created employing a broad range of synthetic processes and a diverse set of chemical building blocks. These kinds exhibit a wide range of physical and chemical characteristics. With this wealth of hydrogel knowledge, scaffold properties like cellular attachment, molecular response, structural integrity, biodegradability, biocompatibility, and solute transport can be precisely engineered to meet the proliferative demands of the construct. Nevertheless, there are still obstacles to overcome in terms of developing appropriate materials for various tissue constructs, as there isn't a one-size-fits-all material that can regenerate all types of tissues due to differences in physiological conditions and specifications[5][17]. A window of opportunity has opened up for the creation of novel materials exhibiting the properties essential for tissue regeneration. Regarding this matter, the possibilities of polysaccharides as appropriate materials for tissue regeneration, with the appropriate modifications to get the needed properties, have neither been well neither investigated nor exhausted.

Polymeric Films

Tissue engineering was the first field to embrace polymer-based coatings due to their ease of production. Over time, occlusive wound dressings made of polymeric films have become more common. Biodegradable polymer films containing wound treatment ingredients have been the subject of much research. You may choose between active and passive treatments for polymeric films. Interactive and occlusive natural polymer films There are two types of synthetic polymer films: passive and active. The non-occlusive bandage only covers the wound. Wounds heal faster with the help of interactive or occlusive polymer coverings because they keep germs at bay. Polymer films may keep a wound bed moist by soaking up exudate from wounds. The body's natural processes of healing and rejuvenation are aided by moisture. To allow air enter and escape the wound bed. Collagen, chitosan, carboxymethyl cellulose, and alginate are some of the most common natural polymers used in wound dressings. Wound dressings made of synthetic polymers have been studied. To enhance mechanical qualities, both natural and synthetic polymers are used, either alone or in combination. Films made of natural polymers are more biodegradable and have lower structural stability. Its first use was to enhance its physical properties using glutaraldehyde. Researchers are looking toward noncytotoxic cross-linkers as chemical cross-linkers damage developing cells. Biologically relevant polymeric films were produced by combining physical and ionic crosslinking techniques. For better bacterial killing and wound healing, use medicines, natural active compounds like quercetin and curcumin, or metal nanoparticles incorporated in polymeric films, such as zinc or silver. Transdermal controlled release made use of the polymeric films that contained the active compounds. The capacity of dynamic self-healing materials to repair themselves, even after extensive deformation, has lately attracted a lot of interest in their research and development. A polyelectrolyte film that can mend itself was detailed, one that uses bacterial cellulose grafted onto poly(acrylic acid). At pH 7.4 and 5.5, the films' self-healing capabilities were examined. After the film was notched, the buffer solution was sprinkled on top. The new film self-healed at pH7.4 and pH5.5. If covalent or ionic connection remains, the material may be able to mend itself. The addition of chitosan to the composite films caused molecules to try to cross the buffer solutions, form an ionic bond with the anionic fillers, and change the cationic bacterialcellulose. The image illustrates the self-healing mechanism of the composite film. Tissue regeneration and engineering are seeing an uptick in the use of polymeric biomaterials with electrical conductivity. A wound dressing film called a "conductive polymeric" was created using sodium alginate and gelatin. The electrical conductivity of the polymeric layer was accomplished by mixing polymers with reduced graphene oxide. High cell adherence and vitality were shown by the findings for the "conductive polymeric" films.

Polymeric Sponges

Recent research has shown that porous scaffolds are useful for tissue engineering. Cell adhesion, The porosity design facilitates vascularization, proliferation, and ECM deposition. By soaking up exudate, porous scaffolds aid in keeping the wound bed wet. Nutrient and gas exchange are both made possible by the interconnected channel system. Drug absorption and release are both facilitated by the structured porous structure. 3D porous scaffolds provide a three-dimensional framework that promotes cell adhesion, proliferation, and differentiation. Academics are now investigating the 3D cell-matrix interactions as a result of this. One common method for making porous biological scaffolds is freeze drying. Furthermore, it is possible that porous scaffolds are more fragile. The pore size parameters for skin and bone tissue engineering are different. Hole sizes ranging from 50 to 200 m were shown to be beneficial for soft tissue engineering techniques and smooth muscles. Sponge materials consisting of both natural and synthetic polymers have been studied for potential use in biomedicine. There has been recent interest in merging natural polymer sponges with synthetic polymers due to their low mechanical strength. Researchers look at crosslinking methods to improve mechanical strength and distribution of pore sizes. A 3D biocomposite macroporous scaffold was created by the researchers using agarose and chitosan. The purpose of testing the 3D scaffold was to determine its potential use in pre-clinical treatment. A link pore architecture of 40–70 m is present in the built scaffolds. Hydrated scaffolds exhibited very minimal form distortion, according to rheological testing, and acted similarly to sponges. Neutral pH enhances cell-cell interaction and hepatocyte colonization, leading to an increase in pore size distribution and mechanical strength of the scaffolds, according to in vitro studies. The researchers also looked at how primary human osteoblasts adhered to and differentiated from deacetylated chitosan sponges. Researchers observed improved cell spreading and differentiation in deacetylated chitosan sponges when tested in vitro. Deacetylated chitosan sponges exhibited more ALP activity compared to non-deacetylated sponges, according to an ALP

experiment. The cytokines and bone markers were measured in the culture media. Quantitative investigation showed that sclerostin and osteoprotegerin expression was improved by decreasing deacetylation of chitosan sponges. Directed bone healing was discovered to have a substantial impact on various chitosan sponges. The use of PVA and PCL in conjunction with other natural polymers for bone tissue engineering has been the subject of extensive research. Drug loading and controlled release also make use of polymeric sponges. Drug loading and dissolution are made possible by polymeric sponges that have a high pore volume and a high porosity. In several studies, the release of drugs is regulated by coating them with an external polymer.

Polysaccharides

As a result of glycosidic bonding between monosaccharides, a wide variety of polymeric compounds derived from plants, animals, and algae are known as polysaccharides. The structure of polysaccharides may be either linear or branched, depending on the kind of monosaccharide unit. Polysaccharides provide a potential for chemical modification due to their structural variety and the presence of reactive groups such as hydroxyl, amino, and carboxylic acid groups [Liu et al. 2008]. Polysaccharides are already quite diverse, and their molecular weights may range from hundreds to thousands of Daltons. The toxicity level of polysaccharides is far lower than that of many synthetic polymers. In most cases, x is a big integer between 200 and 2500 in the general formula of polysaccharides, which is Cx(H2O)y. Given that six-carbon monosaccharides are often found as repeating units in polymer backbones, the general formula may alternatively be written as (C6H10O5)n, with n ranging from 40 to 3000. Polysaccharides, proteins, and nucleic acids are all examples of biopolymers. Their unique chemical structures and characteristics allow them to serve a wide range of purposes. Among the many biological and pharmaceutical uses for polysaccharides, some of the most promising are tissue engineering, post-operative care, wound healing, and the controlled release of pharmaceuticals and proteins. Polysaccharides are useful in many different contexts because they are renewable and may be made from plants and algae, microbial strain cultures, or even recombinant DNA. Additionally, they have the benefits of being biocompatible, non-toxic, and biodegradable due to their biological origin. Furthermore, the structural variety of polysaccharides results in a wide range of useful qualities that are very impossible to replicate in synthetic materials. Polysaccharides are carbohydrates that are chemically generated by linking together repeated sugar units via glycosidic linkages. Both linear and branching architectures are possible in these polymers, which include thousands of sugar moieties.

The physicochemical characteristics of polysaccharides may vary due to the creation of secondary structures; for example, scleroglucan and gellan both exhibit triple helix conformations. Chemical derivatization and functionality modification allow for tailoring the physical and biological characteristics of the parent polysaccharide, thanks to the numerous functional groups present in the monomer units. By creating a network structure with crosslinks between the polymer chains, one may alter the mechanical characteristics.

Numerous polysaccharide-based delivery systems have been used, either alone or in combination with their natural or altered versions, to regulate the release of drugs. These systems include sodium alginate, chitosan, xanthan gum, guar gum, gellan gum, pectin, etc. Composites have come a long way in recent years, thanks to physical and chemical processes including grafting, cross-linking, oxidation, esterification, and combining with other molecules to create novel materials with improved properties. The bio-adhesion properties of polysaccharides have also been used to target certain organs or cells and extend the residence duration of drugs, particularly on mucosal surfaces.

Hydrogen bonding is the primary mechanism by which delivery devices connect with mucosal glycoproteins. Material with a high density of carboxyl and hydroxyl groups, as well as other H-bonding domains, shows promise for medicinal administration. Mucoadhesion is enhanced by polysaccharides and their derivatives, which provide hope for more effective and novel medicinal delivery methods. The use of polysaccharides in drug delivery systems has been on the rise due to all of these characteristics. Furthermore, the polysaccharides' capacity to create hydrogels makes them an attractive candidate for use in tissue engineering. Hydrogels made of polysaccharides provide the perfect conditions for tissue regeneration thanks to their biomimetic capabilities, water-repellent environment, and microporous structure, which allows cells to develop with access to oxygen and nutrients.

Table 1. Classification of polysaccharides.

Classification criteria			Examples
Function	Storage		starch, glycogen
	Structural		cellulose, alginate, chitin, agar
	Secreted		dextran, xanthan gum, pullulan, gellan gum, welan gum, diutan gum
Chemical composition	Homoglycans		starch, glycogen, cellulose, chitin
	Heteroglycans		alginate, carrageenans, gellan, xanthan, agars, arabinoxylans, glycosaminoglycans
Structure	Linear		glycosaminoglycans, cellulose, amylose, pectin, agarose, alginates
	Branched		glykogen, amylopectin, xanthan gum, arabic gum, arabinoxylan
Electrical charge	Neutral		Cellulose, amylose, amylopectin,
	Anionic		alginates, carrageenans, xanthan gum, gellan, gum arabic,
	Cationic		Chitosan
Source	Animals	Mammals	glycosaminoglycans (hyaluronan, heparin, chondroitin sulfate, keratan sulfate)
		Non-mammals	Chitin
	Plants	Higher plants	cellulose, starch
		Algae	agars, alginates,carrageenan,fucoidan
	Microorganisms		gellan gum, xanthan gum
Modification	Pristine		cellulose, alginate, chitin, tamarind kernel polysaccharide
	Derivative		carboxymethyl cellulose, carboxymethyl tamarind, propylene glycol alginate, chitosan
Degradability in humans	Degradable		dextran,glycogen,glycosaminoglycans
	Non-degradable, slowly degradable		cellulose, chitosan, alginate, agar

3. CONCLUSION

When combined with biomolecules, such as medicines or proteins, intelligent polymers have found several intriguing applications in hydrogels, surfaces, and water. Polymeric materials may have their properties and functions tuned by manipulating a variety of structural parameters on microscopic, subatomic, and macro sizes, including the geometry of structured bodies and the self-assembly of macromolecules. Toxin removal, medication administration, enzyme treatments, immunoassays, and affinity separation are all necessary for substantial applications. This review article discusses several forms of smart polymeric biomaterials, as well as biomolecule conjugates of smart polymers on surfaces. The well-known uses of polymer biomaterials, such as implants and medical devices, rely on these bimolecular structures of smart polymers. Engineers have found inspiration in these materials because of their ability to actively react to stimuli and change shape in reaction to them. Biomedical researchers have taken a keen interest in these materials throughout the last two decades, particularly for use in minimally invasive surgeries to implant self-inflating, large medical devices.

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