# A review of polymers for biomedical applications

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**Abstract :**

In addition to their usage in the creation of medical devices, polymer materials hold great promise for advancing several critical biomedical applications, most notably tissue engineering. This paper is comprises of a general review on Biopolymers are natural or synthetic polymers derived from biological source applications. They are safe, less toxic, and comparatively simple. In this paper, Polymer biomaterials are selected for Hard and soft Tissues applications are discussed based on a range of criteria the most important aspect is, biocompatibility. The paper concludes with advancements and in Innovations Biopolymers and the increasingly being used in the development of prosthetic limbs. In addition to Challenges and Future Directions facing biopolymer applications. The criteria for polymeric materials dedicated to biomedical applications are quite stringent and are primarily driven by the safety of their future users and patients.

**Keywords:** Biomedical , Biocompatibility , Polyethylene (PE) , Materials , Biopolymers .

# مراجعة للبوليمرات المستخدمة في التطبيقات الطبية الحيوية

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**الخلاصة :**

تشهد المواد البوليمرية تطوراً هائلا في العديد من التطبيقات الطبية الحيوية الهامة ولا سيما هندسة الأنسجة إضافةً إلى استخدامها في صناعة الأجهزة الطبية. تستعرض هذه المراجعه بصوره عامة حول البوليمرات الحيوية، وهي بوليمرات طبيعية أو اصطناعية مُشتقة من مصادر بيولوجية. تتميز هذه البوليمرات بأنها آمنة، وأقل سمية، وأبسط نسبيًا. في هذه المراجعه، نناقش اختيار المواد البوليمرية الحيوية لتطبيقات الأنسجة الصلبة والرخوة بناءً على مجموعة من المعايير ، حيث يُعد التوافق الحيوي أهمها. وتختتم المراجعه باستعراض التطورات والابتكارات في مجال البوليمرات الحيوية، وتزايد استخدامها في تطوير الأطراف الاصطناعية. بالإضافة إلى التحديات والتوجهات المستقبلية التي تواجه تطبيقات البوليمرات الحيوية. إن معايير اختيار المواد البوليمرية المُخصصة للتطبيقات الطبية الحيوية صارمة للغاية، وتُركز بشكل أساسي على سلامة المرضى الذين سيستخدمونها في المستقبل.

**الكلمات المفتاحية :** الطب الحيوي ، التوافق الحيوي ، البولي إيثيلين، المواد، البوليمرات الحيوية .

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## ١. INTRODUCTION

Bio-based polymeric materials are divided into three classes by source and production process. ١) natural polymers, ٢) bio-based monomers, the second group develops synthetic polymers by ring-opening polymerization or condensation.Whereas, the third group contains polymers ,which are developed through genetically modified bacteria or micro-organisms [١].

Many medical fields make use of polymers, whether they be natural or synthetic, including neurology, urology, dermatology, and bone injury . [٢] In addition to their usage in the creation of medical devices, polymer materials hold great promise for advancing a number of critical biomedical applications, most notably tissue engineering [٣].

Plus, they're not only less harmful, but also easier to use. There are countless prosthetic uses for polymers in medicine, including heart valves, stents, cartilage, and oxygenation of the blood. Smart polymers also play a significant role in cardiopulmonary bypass surgery and other biomedical applications due to their sensitivity to physical conditions and stimulus response nature. Furthermore, they serve as suture materials, tissue adhesives, vascular grafts, cosmetic implant materials, dental composites, contact and intraocular lens materials, etc., scaffolds, joints, artificial skin, blood vessels, uretersal stents, artificial kidney/hemodialysis membranes, and nanoparticle drug delivery systems [٤].

## ٢.POLYMERS FOR HARD TISSUES

### ٢.١ Orthopedic Implants

When a patient suffers a bone fracture anywhere on the body, they need an implant that can mimic the function of the native bone. Hip and knee replacement surgeries are necessary for patients with rheumatoid arthritis and osteoarthritis, two joint illnesses that cause inflammation and pain [٥]. To ensure the implant closely mimics the biomechanical characteristics of bone, integrates with the native tissue, and remains structurally sound for the necessary duration, designers must take the material's biocompatibility, mechanical, surface, chemical, and failure properties into account [٦].

The US Food and Drug Administration defines biocompatibility as the absence of host damage in implant materials, the most essential factor. Due to their close interaction with human tissues, implant materials must be harmless. Good biocompatibility is contingent upon the exceptional resistance to corrosion and attrition in the physiological environment [٧].

The mechanical requirements for orthopedic implant materials are proportional to the working circumstances that are meant to be utilized and the particular applications that are being utilized.

Five essential mechanical parameters are Young's modulus, yield strength, ultimate tensile strength, fracture toughness, and elongation at break. These five mechanical parameters can predict other specific mechanical features like fatigue resistance[٨].

Infection, poor osseointegration, and increased foreign body reaction result from biocompatibility issues. Without mechanical stability, fatigue, stress shielding, and bone resorption occur. Many conventional, coating, and nanomaterials have been employed to stabilize implants[٩].

As interpositional cementing materials between the implant surface and bone, polymers are often utilized in the field of orthopedics. Additionally, polymers are utilized as bearing inserts in hip and knee joint replacements [٧].

After their biocompatibility and mechanical characteristics are optimized, polymers could become a viable option for orthopedic implant applications [١٠]. Many factors influence the selection of polymer biomaterials for use in tissue engineering, such as their molecular weight, material chemistry, surface characteristics, and structure. When choosing a scaffold fabrication technique, it is important to take into account the biomaterials' melting point, solubility, and degradation behavior. Porous structures with strong and modifiable mechanical characteristics may be easily made from polymers, and composites that combine several biomaterials can take advantage of their unique qualities [١١].

Synthetic polymers like polyethylene (PE) and polyether ether ketone (PEEK) are promising for bone implant devices due to their biocompatibility, mechanical strength, and adaptability [١٢]. Pol PE has many advantages as a biomaterial for medical implants and it is used to make porous high-density polyethylene implants for face and cranial reconstruction due to its various medical implant benefits. [١١].

Because of its biocompatibility, high strength, remarkable wear resistance, radiolucency, and elastic modulus that is comparable to human bone, polyetheretherketone (PEEK) is a popular choice. When it comes to orthopedic implants, PEEK is the material of choice. These days, PEEK implants are popping up in all sorts of places: spinal cages, dental implants, joint replacements, fixation devices, implants to address maxillofacial or skull defects, and more[١٠].

### ٢.٢ Dental Applications

The mouth is subject to continuous changes such as variations in pH, temperature, abrasion, and bacterial presence. Despite these challenges, the oral cavity is well-adapted to handle these conditions due to its physiological design, which helps it withstand harsh environments. However, factors like diseases and injuries can affect the function and structure of the teeth and surrounding tissues[١٣].

Polymers used in dentistry are designed to withstand harsh oral conditions such as abrasion, moisture, and temperature changes while maintaining aesthetic appearance and biocompatibility with surrounding tissues. dentistry, polymers are used in several critical applications:Dental Composites:Acrylic Resins: Such as polymethyl methacrylate (PMMA), used in cosmetic fillings [١٤].Composite Resins: A blend of resins and fine fibers, used in cosmetic fillings and restorations.Adhesives:Bonding Resins: Such as acrylic and light-cured resins, used to bond cosmetic fillings to natural teeth.Water-Soluble Adhesives: Used to secure fillings and prosthetics in place.Prosthetic Materials:Polyethylene and Other Polymers: Used in the manufacture of dental prosthetics like crowns and bridges.Flexible Resins: Used in the production of partial dentures [١٥].

Various types of polymers are used for different purposes, including: [١٦-١٨]

١) Acrylic Resins

Polymethyl Methacrylate (PMMA): Used in cosmetic fillings, complete and partial dentures, and dental prosthetics.

Polyethyl Methacrylate (PEMA): Used in some dentures and dental prosthetics.

٢) Composite Resins:

Nano-Composite Resins: Used in cosmetic fillings for their strength and natural appearance.

Light-Cured Composite Resins: Used in fillings and restorations

٣)Bonding Resins:

Light-Cured Acrylic Resins: Used to bond fillings to natural teeth.

Dual-Cured Resins: Cure with both light and chemical reactions, used for bonding.

٤)Adhesives:

Acrylic Adhesives: Used for securing fillings and prosthetics.

Water-Based Adhesives: Also used for securing dental materials.

٥)Flexible Resins:

Polyethylene: Used in partial dentures and removable dentures.

Polyurethane: Used in flexible denture materials.

٦)Other Resins:

Polyethylene Terephthalate (PET): Used in some advanced dental applications.

Polycarbonate: Used in certain dental tools and devices.

## ٣. POLYMERS FOR SOFT TISSUES

### ٣.١ Tissue Engineering

Tissue engineering and regenerative medicine produce materials to replace, restore, or enhance organs and tissues and improve cellular proliferation, migration, and differentiation [١٩]. Many different types of tissues are comprised of soft tissue, including skin, muscles, ligaments, nerves, fascia, intervertebral discs, and blood vessels. For severe soft tissue loss due to congenital abnormalities, illness, accident, or just becoming older, new regenerative treatments are crucial, as are the present methods for reconstituting or regenerating soft tissues[٢٠].

A significant part of the TE tactics is played by the scaffolds. For the purpose of providing a structurally stable environment for tissue regeneration, three-dimensional scaffolds, also known as ٣D scaffolds, have typically been utilized. Extracellular matrix (ECM) is a term that refers to an artificial extracellular matrix. In addition to providing structural support, transferring mechanical pressures, and enabling the transmission of chemical signals, a native ECM is a three-dimensional network whose composition and structure interact with the cells [٢١].

The classic method of biodegradable synthetic polymer scaffold tissue engineering is transplanting cultured cells onto a porous, prefabricated scaffold that is engineered to naturally break down in the body's natural processes [٢٢].

poly(a-hydroxy acid), including poly(glycolic acid) (PGA), poly(lactic acid) (PLA),are common biodegradable polymers in medical applications [٢٣].The most commonly utilized SPs sanctioned by the FDA (Food and Drug Administration of the United States) They are linear aliphatic polyesters that decay by the hydrolysis of their ester bonds, yielding non-toxic compounds and metabolites that may be eliminated by the host's normal metabolism[٢٤].

Polylactic acid (PLA),which was an aliphatic polyester derived from lactic acid (٢-hydroxypropionic acid) [٢٥]. Polymers like synthetic, semi-synthetic, and natural polymers have been added to PLA to create copolymers with biomedical applications [٢٦].Poly (glycolic acid) (PGA) has a similar chemical structure with PLA, but exhibits very different characteristics [٢٧], PGA is one of the accessible, sustainable materials in clinical applications [٢٨].

PGA has been employed as a filler in conjunction with other biodegradable polymers and has been applied in short-term tissue engineering scaffolds for bone, tendon, dental, cartilage, vaginal, intestinal, lymphatic, and spinal regeneration [٢٢].

PGA is an effective nerve regeneration substance. PCL nanofibers were also experimentally studied. When pre-seeded with Schwan cells, these nanofibers allowed neurite development and moderately recovered a ١٤ mm rat sciatic nerve damage model in vivo [٢٠]. PGA and PCL use in Esophagus prosthesis the Application Key features is Tubular knitting of PGA braided yarns and PCL nanofibers. Knitted tubular fabrics have mechanical properties similar to real esophageal tissue also in hyaluronic acid and PGAin Cartilage formation, Collagen and PGAin Bone defect healing, PCL, Tea polyphenol, PLA and PGA in Drug release ,PLA and PGA in Acupoint catgut embedding therapy application,PGA and fibrin in Partial glossectomy,Poly (ethylene terephthalate) (PET) and PGAin Drug-eluting vascular graft and PLA and PGAin Treatment of noncontained human periodontal infrabony defects etc [٢٨] .In addition to PLA Scaffolds use for Nervous ,Cardiovascular ,Cutaneous Tissue Engineering [٢٩].

### ٣.٢ Drug Delivery Systems

One potential alternative to traditional drug delivery vehicles is polymeric micro/nanoparticles (MPs/NPs), particularly those formulated with biodegradable polymer. These have the ability to transport macromolecular medicines [٣٠].

(I) These particles may safeguard encapsulated macromolecular drugs from chemical and enzymatic degradation, thereby prolonging their half-life in vivo; (II) their diminutive size may facilitate the circumvention of physiological barriers, such as the blood-brain barrier and cell membranes; (III) the biodegradability of these particles confers sustained and controlled release; (IV) the plethora of surface modification techniques available may allow for targeted delivery to specific organs, tissues, cell groups, or focal areas, potentially enhancing delivery efficiency and minimizing side effects and drug dosages [٣١].

There are three mechanisms that control the release of drugs from biodegradable polymers: (١) surface erosion, (٢) cleavage of surface or bulk polymer bonds, or (٣) diffusion of the physically entrapped drug. But frequently all three are involved at the same time, leading to drug release [٣٢].

One of the most popular biodegradable polymers is poly(D,L-lactic-co-glycolic acid), or PLGA. It is typically made through the ringopen co-polymerization of glycolide and lactide [٣٣].

The endogenous nature and facile metabolism of these two monomers through the Krebs cycle result in low systemic toxicity when employing PLGA for medication administration or biomaterial applications. PLGA has received approval from the US FDA and the European Medicines Agency (EMA) for several medication delivery methods in humans[٣٤].

Moreover, various studies show that PLGA can be easily shaped into drug-carrying devices at any size (e.g., nanospheres, microspheres, or even millimeter-sized implants), can encapsulate various drugs, peptides, or proteins, and can be delivered over various time intervals using diverse delivery routes[٣٥].MW, lactide-to-glycide ratio, and drug concentration can influence PLGA's drug release. PLA is more hydrophobic than PGA due to the additional methyl group in its side chain, hence more PLA means less water absorption and slower breakdown [٣٦].

Block copolymers of PLGA and PEG (PLGA−PEG) were created to enhance in vivo circulation and biocompatibility of PLGA NPs. PLGA−PEG diblocks (AB) or copolymers (ABA) are utilized to create NPs or thermogels [٣٢].currently developed PLGA-based nanoparticles as drug delivery systems for the treatment of different pathologies.Examples include:

In the context of inflammatory bowel disease (IBD), PLGA nanocarriers may be utilized to provide a delivery system for anti-inflammatory medications, such as glucocorticoids, targeting arthritic lesions, treating ocular inflammatory conditions, and facilitating effective drug transport to the central nervous system. The initial treatment option for cardiovascular disease is the insertion of a stent. Stents may be coated with PLGA-based nanoparticles that encapsulate specific medicines, genes, or proteins, facilitating a gradual release of these therapies[٣٤].

## ٤.POLYMERS IN PROSTHETIC LIMBS

### ٤.١. Design and Materials Selection

Biopolymers are natural or synthetic polymers derived from biological sources that are increasingly being used in the development of prosthetic limbs. They offer several advantages[٣٧]:

١) Biocompatibility: Biopolymers are often well-tolerated by the human body, reducing the risk of rejection or adverse reactions.

٢) Sustainability: Many biopolymers are derived from renewable resources, making them more environmentally friendly compared to conventional synthetic materials.

٣) Customization: Biopolymers can be engineered to have specific mechanical properties, such as flexibility, strength, and durability, which can be tailored to meet individual needs in prosthetic limbs.

٤) Weight and Comfort: These materials can be lighter than traditional materials, potentially increasing comfort and ease of use.

٥) Examples of biopolymers used in prosthetics include silicone, polyurethane, polylactic acid (PLA), polyglycolic acid (PGA), and chitosan. Research continues into improving the properties of these materials and exploring new types that can enhance the functionality and comfort of prosthetic limbs[٣٨].

### ٤.٢Advancements and Innovations

In the recent decade, Prosthetics and Orthotics (P&O) have adopted bionic technology, improving patient mobility [٣٩]. The emergence of ٣D printing in the prosthetics business has permitted several creative approaches to old duties and novel solutions to challenges that traditional technologies cannot solve [٤٠].

An essential component of a prosthetic is the socket, which receives its load from the residual limb and distributes it to the prosthesis. Composite materials, including carbon fiber particles and distal reinforcement implemented by a compositing infill approach, seem to enhance the robustness of ٣D printed sockets [٤١].

Thus, the ٣D printer can quickly create prostheses with the appropriate mechanical and physical qualities and patient compatibility. Ear, nose, teeth, bone, hand, and foot prostheses are realistic, fit the patient's anatomy, and match the original mechanical qualities. Additionally, multi-material printing allows prosthesis users to match their skin pigmentation [٤٢].

The complexity of printed sensor systems will inevitably approach that of integrated circuits or even nature when ٣D printers are able to deposit an ever-increasing range of materials with improved resolutions. Artificial intelligence (AI) coupled with similarly complicated actuators and sensor systems might bring these systems closer to mimicking the sensing and manipulating capabilities of nature in practical settings[٤٣].

To present, multiple ٣D printing technologies have been used to make piezoresistive, capacitive, and piezoelectric tactile sensors [٤٤]. Here, ٣D printing can be used to manufacture products quickly and cheaply and to add functionality by engineering materials, which add complexity to the product's structural or chemical qualities[٤٥]. Tissue engineering is finding more and more uses with the advent of ٣D printing. Using a variety of methods, biocompatible materials might be ٣D printed as scaffolds, opening up ranges of sizes from millimeters to nanometers. When compared to more conventional methods, three-dimensional printing has several benefits, such as increased production and the elimination of porogen leaching. Various types of soft tissue, including vascular grafts, tracheal splints, multilayered skin, heart tissue, and cartilage constructions, were created and transplanted via ٣D printing [٢٠].

## ٥.CHALLENGES AND FUTURE DIRECTIONS

Biomaterials made of natural or synthetic polymers are approved for internal use after extensive in vitro testing[٢]. Polymeric polymers for biomedical uses must meet strict safety standards for patients. ISO ١٠٩٩٣ standardizes them [٤٦]. Proper material selection, manufacturing, sterilization, and bodily impacts are considered. Biocompatibility evaluations are required for all biomaterials used in live organisms. Implants, scaffolds that touch blood, tissues, membranes, or skin, are tested for cytotoxicity, blood compatibility, carcinogenicity, biodegradability, sensitization, and cell reactivity [٢].

Advances in polymer research and engineering have led scientists to focus on ecologically friendly materials to reduce the environmental impact of synthetic plastics [١] degradable polymers attracted considerable attention in medical applications because they exhibited advantages over the non-biodegradable polymers [٢٥]. Biopolymers are environmentally friendly, chemically adaptable, sustainable, biocompatible, biodegradable, and fundamentally useful. These biopolymers are sourced from renewable materials such as biomass, corn, sugarcane, and molasses [١].

Degradation causes these polymers to crystallize more and decreases their molecular weight and pH. Countless biomedical fields rely on biodegradable polymers, including urology, heart surgery, controlled drug delivery systems, tissue engineering and regenerative medicine, dentistry, orthopedics, and countless more [٢].

The significance of biodegradable polymers in modern medicine is increasing at an exponential rate due to the continuous progress in micro medication delivery to specific organs. Because they degrade into harmless carbon dioxide and water, the US FDA has given its stamp of approval to poly(lactic acid), poly(glycolic acid), and poly(lactic-co-glycolic acid), or PLA, for specific medical uses [٤] .Besides these, biopolymers have bactericidal or virucidal action, make them ideal for absorbing and removing specific chemical pollutants, and are thus potential materials for various filter applications. One effective technique for managing bleeding is the use of topical hemostatic drugs through various biopolymers to control excessive blood loss [٤٧].

Biodegradable biopolymers have come a long way, but there are still some unanswered questions that need to be answered. Tissue biomimicry is an ongoing and significant obstacle in the biomedical field. Consequently, ٣D printing organs or tissues made of biopolymers necessitates further research and development. This is because there are a number of obstacles in the way, including issues with biosafety and environmental safety, printability of materials, functionality, and precise organ shape [١].

Biodegradable polymer materials used in medical applications may experience electric fields, varied stresses and strains, temperature, flow, and pressure, among other things, depending on their location and function. Adaptability and resistance to various stimuli are the materials' top priorities. The most difficult aspects to understand and address are these. Research into chemical alterations and the development of hybrid polymer biocomposites with the potential to mimic and regenerate soft tissues and/or bone should continue [٤٨].

Despite the many successes that have already been achieved, but many questions remain. These will continue into the future, revealing new and possibly unforeseen difficulties and challenges. [٢]. Considering the earnest effort to environmental protection, biodegradable polymers' future looks bright[٤٩].

## ٦. CONCLUSIONS

Academic researchers in biopolymers often work in physics, soft matter, chemistry, biochemistry, and biology have abilities to convey their knowledge. Thus, these talents should help them overcome major obstacles including comprehending life's physics, designing nanoscale functional smart materials, assembling extended structures with desired attributes, and physics far from equilibrium. A biomimetic approach to biopolymer synthesis may require extensive genetic engineering tool development due to the gap between nature and scientist knowledge of “tailor-made” biopolymers. Biopolymer life cycles, which are not always their sole component, should be considered to prevent the problems we face with fossil fuel-based homologues

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