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Biodegradable Polymers and Their Applications in Medicine

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Abstract:
Biodegradable polymers have emerged as one of the most significant materials in contemporary medicinal applications as these polymers can degrade within the human body into non-toxic by-products after their work is done. In contrast to conventional plastics, no second surgery is required for removal of these materials. Their properties can be altered to suit particular conditions. This includes degradation rate, mechanical strength and drug-release profile. The key types of biodegradable polymers, their degradation mechanisms and expanding utility in drug delivery, tissue engineering, orthopaedic implants, wound dressing and cardiovascular devices are highlighted in this paper. As a result of recent advances, appropriate PEGylation of polylactic acid microspheres, biodegradable conducting polymers for bioelectronics, polymer scaffolds for regenerative medicine, etc. The paper also discusses contemporary challenges, such as the body's immune response to some polymers and the difficulty of matching degradation rate to tissue healing rate and Lastly , research future directions.

Keywords: biodegradable polymers, biomedical applications, drug delivery, tissue engineering, regenerative medicine, polylactic acid, biocompatibility

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INTRODUCTION

In today's era, polymers play an important role in healthcare delivery from the simplest suture material to the most complicated, like drug-delivery vehicles and tissue scaffolds. Biodegradable polymers are designed to degrade in the body by hydrolysis and/or enzymatic action. They decompose in the body to yield water, carbon dioxide, and other metabolites that are not toxic. The body can further eliminate these metabolites. The property of being degradable eliminates the need for additional surgeries to extract implants, which is a major advantage over their permanent biomaterials such as metals and non-degradable plastics. A biomaterial is generally understood as a substance engineered to interact with biological systems. The intended purpose of that interaction is in the context of treating, diagnosing or replacing tissue or organ function (Kurowiak, Klekiel, & Będziński, 2023, Introduction section). Biodegradable polymers belong to this group; they are only temporary, meaning they will support the body for as long as needed and then disappear. Because of this property, they are especially useful in orthopedics, cardiovascular medicine, drug delivery and tissue engineering.

The market data reflects the increasing global demand for these materials. The global biomaterials market (biodegradable polymers), which was valued at nearly USD 35.5 billion in 2020, is estimated to reach over USD 47.5 billion by 2025. This growth will be primarily driven by increasing incidence of cardiovascular disease and the rising adoption of medical implants (Oleksy, Dynarowicz, & Aebisher, 2023, p. 2). Comparable development is anticipated in the market for regenerative implantation surgery, tissue repair and therapeutic cell culturing, which relies on biodegradable scaffolds. Overall, this market was valued at approximately USD 23 billion and is anticipated to reach about USD 94.2 billion at the conclusion of 2025 (Mondschein, Kanungo, & Montclare, 2019, p. 1).The objective of this paper is to give an update on the different kinds of biodegradable polymers used in medicine, their possible degradations and their applications, according to some new discoveries (2023-2025).

Classification of Biodegradable Polymers

Biodegradable polymers used in medicine can be broadly classified into natural and synthetic ones. Substances such as collagen, chitosan, alginate, hyaluronic acid and cellulose derivatives are naturally biodegradable polymers. These materials are usually made from plants, animals or microbes. It has good biocompatibility as they are made from constituents found in human tissue. Due to their effective support of cell attachment and proliferation, they are preferred over synthetic materials in wound healing and tissue engineering applications.

On the other hand, synthetic biodegradable polymers are produced synthetically and include polylactic acid (PLA), polyglycolic acid (PGA), poly (lactic-co-glycolic acid) (PLGA) and polycaprolactone (PCL). The ability to control the molecular weight, crystallinity and degradation rate of the monomers during synthesis makes these polymers attractive for industrial and clinical applications. It allows for reproducible, large-scale synthesis (Liu, Hou, & Yang, 2025, Introduction section). For example, polycaprolactone could be thermally processed using conventional thermal processing methods due to a low melting (Tm) and glass transition (Tg) temperature. It shows familiar flexibility for soft-tissue applications (Bhagia et al. 2025, 3).Applying biocompatibility and biodegradability strategies to natural versus synthetic polymers negates the natural polymer’s lack of mechanical strength or the sites for cell interaction in synthetic polymers (Asghari, Samiei, Montazerabadi, & Akbarzadeh, 2024, Discussion).

Degradation Mechanisms

The biological degradation of biodegradable polymers takes place mainly by two mechanisms, i.e. hydrolytic degradation and enzymatic degradation. Water molecules, in the process known as hydrolytic degradation, attack on polymer backbone’s ester of amide bond and break this one by one long polymer chains into shorter chains and finally into monomers that a cell can metabolize or excrete. The hydrolytic pathway is the main reason for the degradation of polyesters like PLA, PGA, and PLGA. In contrast, enzymes like lipases and proteases that occur in nature can break polymer chains. This pathway applies more to natural polymers, like collagen and chitosan, since the human body has enzymes that can recognize and degrade those that are biological.

The degradation rate relies on many factors including crystallinity, molecular weight, hydrophobicity, and surroundings which include pH, temperature, and other biochemical conditions. The fact that one of the strongest points of synthetic biodegradable polymers is their tunability. That is, manufacturers can modulate the ratio of monomers. For example, the lactide-to-glycoside ratio in PLGA, to produce rates of degradation to range from a just a few weeks to several years depending on the clinical need (Mondschein et al., 2019, p. 4).

Applications in Medicine

Drug Delivery Systems

The majority of biodegradable polymer formulations have been developed for drug delivery applications.

Polymers like PLGA and PLA are often used to encapsulate drugs in microspheres, nanoparticles or implants that release their payload as the polymer disintegrates. The controlled release leads to less frequent dosing and better adherence by patients; it can target specific tissues to reduce systemic side effects. According to a full-fledged review of drug delivery systems, various biodegradable polymers continue to remain at the floral phase of designing sustained-release inject able formulations, implantable depots and chemotherapy and other nanoparticles carrier used for chronic diseases (Mathane, Hatwar & Bakal, 2025, p. 201).Newer polymers for drug delivery were developed to overcome limitations of older systems. An example is the surface modification of PLA microspheres with short PEG chains which has been shown to enhance histocompatibility by lessening the tissue inflammatory response caused by unmodified PLA after implantation (Liu et al. cited in Asghari et al. 2024, Section 3). Simultaneously, however, researchers are worried about pre-existing or treatment-induced anti-PEG antibodies that modify the distribution of PEGylated nanocarriers throughout the body, triggering unwanted inflammatory or hypersensitivity effects (Asghari et al., 2024, Section 3). The finding indicates that even well-established modification strategies need to be re-evaluated as additional clinical data becomes available.

Regenerative Medicine and Tissue Engineering.

Biodegradable polymers are used as scaffolds to tissue engineer cells. Scaffolds are 3D structures that can sustain the attachment, growth and differentiation of cells. As the engineered tissue matures and begins to fulfill the mechanical and biological function of the scaffold, the polymer gradually degrades and is absorbed in the body, so that at the end only natural tissue remains.

The biodegradable polymers are still cornerstones of drug delivery, tissue engineering, and regenerative medicine according to the editorial comment on the recent biomedical polymers research (Yang, Hu, & Jiang, 2025, Abstract). They are useful because of their biocompatibility and tunable mechanical properties. Bio-degradable polymer-based hydro gels are studied for their application in dealing with skin photo aging. As a highly compatible soft hydro gels, it can retain moisture and mimic the extracellular matrix. This helps to regenerate skin tissue. However, the clinical utility of the hydrogels is limited due to stability issues (Yang et al., 2025, Section 2).

Implants for Bone and Heart.

In the field of orthopedics, biodegradable polyesters are utilized in the construction of fixation devices like screws, pins and plates which help in stabilizing fracture. Unlike metal implants, which require a second surgery to remove the hardware following the healing of the bone, these devices get degraded over time, thus, getting rid of the second surgery. Biodegradable polyesters are very attractive for such applications because they can be prepared reproducibly and at low cost over a range with desired mechanical and degradation properties for use in various clinical settings (Mondschein et al., 2019, p. 2).

In the field of cardiology, bioresorbable vascular scaffolds have been made using biodegradable polymers. These scaffolds work by supporting a blood vessel after angioplasty. It then gradually bioresorbs itself once the blood vessel healed. Moreover, this can reduce complications with permanent metallic stents. Chronically inflammatory response and late stent thrombosis are some of those complications.

Bioelectronics and rising applications

The relatively newer application area that is developing rapidly is associated with biodegradable conducting polymers that are being developed for its electrical conductivity and the ability to degrade safely in the body. Researchers are investigating these materials for advanced applications in transient implantable electronics, biomedical imaging devices, and short-term postoperative monitoring sensors. The recent advancement of the transient implantable electronics for postsurgical preventive medicine will allow monitoring recovery of a patient and will just disappear without removal surgery (Mirzajani et al., 2025, search results). According to scientists, many large polymer molecules are already employed in positioning prosthetics due to their lightweight and flexible characteristics.

Antibacterial Applications and Wounds Care

Biodegradable polymers are also heavily used in coatings and wound dressings. Polymer-based dressings can be filled with antimicrobial agents or metallic nanoparticles, such as silver, zinc or copper, to enhance their antibacterial performance while the polymer scaffold promotes tissue regeneration at the wound site (Oleksy et al., 2023, p. 6). These multifunctional dressings can control infection, maintain moisture for optimal healing, and degrade to allow for new skin growth underneath.

Obstacles and Upcoming Pathways

Biodegradable polymer are facing challenges in many places despite the use of them. It remains challenging to match the degradation rate of a polymer with the healing rate of the surrounding tissues. A scaffold that degrades too quickly may not be able to provide adequate mechanical support. On the other hand, one that degrades too slowly may hinder new tissue formation. Furthermore, some polymers – like PLA – are biocompatible, yet they may elicit inflammation or other adverse tissue responses in some patients (Asghari et al., 2024, Section 3). Thirdly, the immune response to common modification strategies, such as PEGylation, is highly unpredictable as anti-PEG antibodies may appear (Asghari et al., 2024, Section 3). These could then compromise the safety of the nano medicine formulation.

In future studies, more and more researchers are developing smart, stimuli-responsive biodegradable polymers that can change their degradation behavior or drug-release profile in response to defined biological triggers such as pH or enzyme concentration at the disease site. As well as balancing a material's biocompatibility with mechanical performance, researchers are also keen to combine natural and synthetic polymers. Custom-designed biodegradable conducting polymers could also be used in next-generation bioelectronic implants.

Conclusion

Biodegradable polymers have transformed multiple areas of medicine by offering materials that perform a clinical function and then safely disappear from the body. From controlled drug delivery and tissue engineering scaffolds to orthopedic fixation devices, cardiovascular scaffolds, and emerging bioelectronic implants, these materials continue to expand the possibilities of modern healthcare. Recent research demonstrates both significant progress, such as improved histocompatibility through surface modification, and ongoing challenges, such as unpredictable immune responses to certain polymer modifications. Continued interdisciplinary research combining polymer chemistry, immunology, and clinical medicine will be essential to fully realize the potential of biodegradable polymers in future therapeutic and diagnostic applications.

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