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A BRIEF REVIEW OF BIODEGRADABLE POLYMERS USED IN CARDIAC REPAIR

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Abstract

Biodegradable polymers represent a significant innovation in cardiac repair, having varied applications in myocardial regeneration, controlled drug delivery, and blood vessel repair. These polymers provide temporary structural support, facilitating tissue regeneration and eliminating the need for additional surgery. Natural polymers, such as collagen and chitosan, excel through biocompatibility, while synthetic polymers, such as PLA and PLGA, provide control over mechanical properties and degradation rates. However, challenges such as inflammatory reactions and incomplete integration with host tissues underscore the need for further research. Future directions include the development of hybrid materials, the integration of nanotechnology, and the design of smart devices capable of responding to specific stimuli. Biodegradable polymers have the potential to revolutionize cardiovascular treatments, providing personalized and effective solutions that improve clinical outcomes and patients' quality of life.

Keywords: Biodegradable polymers, cardiac regeneration, biomaterials, bioresorbable stents, controlled delivery, hybrid materials.

Introduction

Cardiovascular disease (CVD) is the leading cause of mortality worldwide, generating an urgent need for innovative solutions for the repair and regeneration of affected heart tissue. In this context, biodegradable materials have gained significant interest due to their ability to support tissue regeneration while reducing the risks associated with permanent materials. Biodegradable polymers, both natural and synthetic, play a key role in the development of biomedical devices used for cardiac repair, including regeneration scaffolds, injectable hydrogels, and drug delivery systems. These materials are designed to provide temporary structural support, facilitating cardiac cell regeneration and integration with host tissue before degrading into inert substances, which are metabolized or eliminated from the body [1-3].

The unique feature of biodegradable polymers lies in their ability to mimic the natural properties of the extracellular matrix, providing an optimal environment for cell attachment, proliferation, and differentiation. Natural polymers, such as collagen, chitosan, and gelatin, are recognized for their high biocompatibility and ability to mimic the structure of native tissues. However, their use is limited by batch variability and uneven degradation. On the other hand, synthetic polymers, such as polylactide (PLA), polyglycolide (PGA), and PLGA-type

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copolymers, offer increased flexibility in adjusting mechanical properties and degradation rates, but their degradation products can cause inflammatory reactions [1-5].

In cardiac engineering, biodegradable polymers have a wide range of applications, from myocardial regeneration to blood vessel repair and delivery of therapeutic factors. For example, injectable hydrogels made from biodegradable polymers can be used to deliver stem cells or growth factors directly into the affected heart tissue, stimulating regeneration. At the same time, biodegradable three-dimensional matrices serve as temporary scaffolds that facilitate the formation of new functional myocardial tissue. At the same time, these materials are used in stents and biodegradable vascular grafts, providing temporary mechanical support and reducing the risk of long-term complications, such as restenosis [1,3-5].

The continued development of biodegradable polymers is driven by the growing demands for customized materials that meet the specific needs of patients and integrate modern technologies such as 3D printing and nanotechnology. However, the implementation of these materials in clinical practice is still limited by challenges such as precise degradation control and potential side effects. Despite these obstacles, biodegradable polymers have the potential to revolutionize current treatment approaches in cardiology, providing effective and safe solutions for tissue repair [2-6].

This review aims to provide an overview of the types of biodegradable polymers used in cardiac repair, highlighting their advantages and limitations, as well as prospects in this field. By analyzing their fundamental characteristics and practical applications, this study emphasizes the importance of further research to optimize these materials to improve clinical outcomes.

Types of biodegradable polymers

Biodegradable polymers are an essential category of materials used in cardiac repair, due to their ability to degrade into non-toxic, naturally eliminable products from the body. These polymers can be classified into two broad categories: natural polymers and synthetic polymers, each of which has specific advantages and limitations that influence their use in tissue engineering [3-6].

Natural polymers, such as collagen, chitosan, gelatin, alginate, and hyaluronic acid, are derived from biological sources, which gives them excellent biocompatibility. Collagen, a major component of the extracellular matrix, is commonly used for scaffolds due to its mechanical properties and ability to support cell attachment. Chitosan, derived from the shells of crustaceans, is prized for its antimicrobial properties and ability to promote angiogenesis. Gelatin, a derivative of collagen, is used in hydrogels due to its controllable degradation and high bioactivity. Alginate, extracted from seaweed, is used in injectable applications for cell or drug delivery, while hyaluronic acid plays a crucial role in supporting tissue regeneration due to its involvement in cell signaling [3-7].

However, natural polymers have some drawbacks, such as composition variability between batches and unpredictable degradation rates. In addition, manipulating them to obtain specific mechanical properties or to control degradation can be difficult, limiting their applicability in certain clinical contexts [2,4-8].

Synthetic polymers, such as polylactide (PLA), polyglycolide (PGA), PLGA copolymers, and polycaprolactone (PCL), provide more precise control over mechanical properties, structure and degradation rates. PLA and PGA are commonly used due to their biocompatibility and ability to support heart tissue regeneration. PLGA, a copolymer of PLA and PGA, allows for the adjustment of degradation rates and controlled drug release, making it ideal for applications in growth factor delivery or other regenerative therapies. PCL, with a slower degradation rate, is used in devices that require long-term support, such as structural matrices [4-8].

Table 1. The table presents the classification of biodegradable polymers used in cardiac repair, dividing them into natural, synthetic, and hybrid polymers. Each category includes relevant examples, key properties, clinical applications, and limitations, highlighting their contributions to myocardial regeneration, the delivery of bioresorbable drugs and devices, as well as the challenges associated with their use in medical practice [3-11].

Category	Examples of polymers	Key properties	Clinical applications	Limitations
Natural polymers	Collagen, Chitosan, Gelatin	High biocompatibility, mimics the natural extracellular matrix	Scaffolds for myocardial regeneration, injectable hydrogels	Uncontrolled degradation, variability between batches
Synthetic polymers	PLA, PGA, PLGA, PCL	Control over mechanical properties and degradation rates	Bioresorbable stents, drug delivery systems	Potentially inflammatory degradation products
Hybrid materials	PLA-collagen, PLGA-chitosan	Combination of biocompatibility and structural control	Customized scaffolds, smart devices	Complex manufacturing process

The main advantage of synthetic polymers is their high reproducibility and flexibility in design, allowing materials to be customized to the patient's needs. However, their breakdown products, such as lactic acid and glycolic acid, can cause local inflammatory reactions in some cases, which require careful monitoring and further optimization [7-11].

Although natural polymers excel in biocompatibility and bioactivity, synthetic polymers are preferred in applications that require customization and rigorous control of mechanical properties. The integration of the two types of polymers in hybrid materials begins to offer promising solutions, combining their advantages to achieve superior performance, the choice of the appropriate polymer depends on the specific requirements of the clinical application, and the development of new hybrid or functionalized materials remains a key direction in biomedical research [7-12].

Mechanisms of action and clinical applications

Biodegradable polymers play a crucial role in cardiac repair through well-defined mechanisms that facilitate tissue regeneration, supporting the biological processes necessary for the restoration of cardiac function. These polymers are used in a variety of clinical applications, including myocardial regeneration, controlled drug delivery, and blood vessel repair, thus helping to address the multiple challenges associated with cardiovascular disease [8-13].

A major application of biodegradable polymers is their use in the creation of scaffolds (three-dimensional matrices) that serve as temporary structural support for the regeneration of heart cells. These matrices are designed to mimic the properties of the natural extracellular matrix, facilitating the attachment, proliferation, and differentiation of myocardial cells. For example, injectable hydrogels made of polymers such as collagen or PLGA are used to deliver stem cells or cardiomyocytes directly into the affected heart tissue, stimulating regeneration and reducing the size of post-infarction scars. The properties of these hydrogels, such as porosity and degradation rate, can be adjusted to optimize the gradual release of growth factors or cells [9-14].

Biodegradable polymers are essential in the development of controlled drug delivery systems for cardiac treatments. For example, microparticles and nanoparticles made from

PLGA are used for the gradual release of growth factors, such as VEGF (vascular endothelial growth factor), which stimulate angiogenesis and promote blood vessel regeneration. These systems ensure a localized and controlled release, minimizing systemic adverse effects and increasing the effectiveness of the treatment. In addition, biodegradable polymers are also used to deliver anti-inflammatory or antifibrotic drugs, reducing side effects and improving integration with host tissue [7,10-15].

Another important area of application of biodegradable polymers is blood vessel repair, where they are used in vascular grafts and bioresorbable stents. Stents made of polylactide (PLA) provide temporary mechanical support for the affected blood vessels, preventing them from collapsing until the vascular tissue is restored. After performing their function, these stents degrade completely, eliminating the risk of long-term complications such as restenosis or chronic inflammation. Biodegradable polymers are also used to create porous vascular grafts that support angiogenesis and integration with neighboring tissues [11-16].

A major advantage of using biodegradable polymers in these applications is the reduction of risks associated with permanent materials, such as chronic inflammation or the need for additional surgery to remove the devices. In addition, they allow for increased customization, being tailored to meet the specific needs of each patient. Their integration with advanced technologies, such as nanotechnology and 3D printing, opens up new opportunities for developing more efficient and affordable solutions [7,12-17].

The mechanisms of action and clinical applications of biodegradable polymers demonstrate their immense potential in treating cardiovascular diseases. Further research in this area is essential to optimize the performance of these materials and expand their use in practice [13-18].

Advantages and limitations of biodegradable polymers

Biodegradable polymers are essential in cardiac engineering due to their ability to support tissue regeneration, deliver therapies, and degrade naturally. They provide temporary structural support, facilitating myocardial regeneration and eliminating the need for surgical removal. Synthetic polymers, such as PLA and PLGA, provide control over drug degradation and release by being tailored to the specific requirements of patients. They also reduce the risks associated with permanent materials, such as chronic inflammation or vessel restenosis [12-21].

Table 2. The main advantages and limitations of biodegradable polymers according to their category: natural, synthetic, and hybrid. Properties such as biocompatibility, degradation control, and production complexity are highlighted, alongside specific clinical applications such as myocardial regeneration, drug delivery, and use in bioresorbable devices, highlighting the challenges associated with each category [12-21].

Aspect	Natural polymers	Synthetic polymers	Hybrid materials
Biocompatibility	High	Moderate	High/moderate, depending on design
Control over degradation	Limited	Very good	Good
Inflammatory risk	Low	Potentially high	Variable
Production complexity	Low	High	Very high
Typical applications	Myocardial regeneration, hydrogels	Stents, drug delivery systems	Customized scaffolds, smart devices

However, biodegradable polymers have limitations, including the risk of inflammatory reactions caused by degradation products such as lactic acid. Natural polymers have high batch-to-batch variability, and incomplete integration with host tissues remains a challenge, especially for hydrophobic synthetic materials. High costs and complex production limit their accessibility [18-21].

Conclusions

Biodegradable polymers have become a central pillar in modern approaches to cardiac repair, offering innovative and personalized solutions in the treatment of cardiovascular diseases. Through their ability to support tissue regeneration, deliver drugs in a controlled manner, and temporarily integrate into the body, these materials eliminate many of the limitations associated with permanent devices. Both natural and synthetic polymers have demonstrated valuable applications in myocardial regeneration, blood vessel repair, and the development of stents or bioresorbable vascular grafts.

However, their use is not without its challenges. Local inflammatory reactions, incomplete integration with host tissues, and variability in the properties of some polymers are obstacles that sometimes limit the application of these materials in clinical practice. These limitations underscore the need for continued research to optimize physicochemical properties, reduce adverse effects, and improve clinical performance.

The development of hybrid materials and the introduction of advanced technologies, such as 3D printing and nanotechnology, open up new perspectives in the use of biodegradable polymers. The design of smart devices, capable of responding to biological or physical stimuli, is a promising direction for improving their effectiveness and safety.

Biodegradable polymers offer a versatile and effective platform for solving the multiple challenges in the field of regenerative cardiology. The integration of these materials with technological innovations and the development of customized solutions will transform the way cardiovascular diseases are treated in the future, contributing to a significant improvement in the quality of life of patients.

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