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The role of polymers in genetic engineering and biotechnology applications/ A Review Article

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Abstract: **Background:** The review presents how polymers play their roles in genetic engineering and biotechnological applications, including gene transfer, CRISPR-Cas9-mediated gene editing, vaccine development, and regenerative medicine. To explain how polymers contribute to the improvement of such technologies, various research methods were used, including literature review and case studies. **Methodology**: The most effective vectors, transporting DNA into cells and at the same time giving less cytotoxicity to improve the gene transfer process, include polymers like polyethylene and polylysine, CRISPR-Cas9 Gene Editing: The use of polymers has been done in improving the delivery of CRISPR-Cas9 components into the target cells, which would enhance the precision of gene editing while reducing nonspecific side effects. The active principle of vaccines, like COVID-19 vaccines, contains mRNA enveloped in a protective layer of polymers to avoid DNA degradation and increase immune response, regenerative medicine and tissue engineering, where biodegradable polymers are used as temporary matrices to support the growth of new tissues, especially in the treatments of injuries and chronic diseases. They are also being used in the manufacture of sensors for the detection of biological molecules such as proteins and DNA. **Conclusions**: Polymers have been used in a number of ways in order to enhance the effectiveness of genetic engineering and biotechnology techniques, including improving gene transfer, gene editing, vaccine development, and regenerative medicine. Further research is foreseen to be directed at developing smart polymers that will enhance the precision and efficiency of such applications.

Keywords: Polymers, Genetic Engineering, CRISPR-Cas9, Vaccines, Regenerative Medicine

Introduction

These are big molecules with repeating units, finding wide application in many scientific and medical fields, including genetic engineering and biotechnology[1]. The possibility of their chemical modification, together with a wide range of physical properties, makes them ideal materials for improving gene transfer and drug delivery and developing gene therapies and regenerative technologies. The role of polymers in some of the fundamental applications of genetic engineering and biotechnology will be discussed in this article, focusing on their contribution to improving gene therapies and vaccines, with some innovative solutions in regenerative medicine[2].

1. Polymers in Gene Transfer

Gene transfer is among the most common applications of polymers within genetic engineering. Traditionally, viruses had been employed to carry genetic material into the cells, while nowadays, polymers are a good and much safer option according [3].

1.1 Therapeutic Gene Transfer: The positive polymers, such as polyethylene imine and poly-lysine, are widely used for DNA or RNA transfer into the cells. These polymers bind DNA in a very firm way and protect it from degradation while crossing the cell membrane. This technology is widely used in gene therapies that are applied for the treatment of genetic diseases such as cystic fibrosis and some types of cancer.

1.2 Chemical improvements of polymers

The chemical structure of the polymers is modified to make them more biocompatible and reduce cytotoxicity. Such modifications include the addition of nonpolar groups to the polymers, one of the ways to enhance cell penetration for more efficient gene delivery.

2. Polymers and gene editing using CRISPR-Cas9: CRISPR-Cas9 is one of the most powerful gene-editing technologies. However, this system is also facing a technical problem in delivering the gene system to the target cells. This is where polymers come into play to enhance the delivery efficiency of those genetic tools according to [4].

2.1 Polymers in improving CRISPR delivery:

Polymers can protect the components of the CRISPR-Cas9 system, such as guide RNA and proteins, from degradation before their arrival at the target cells. The modification of polymers could be performed in a manner that gene editing takes place only inside the target cell for enhanced precision in gene editing with minimal side effects.

2.2 Smart polymers:

The ongoing effort for this goal has led to the development of smart polymers that can respond to a temperature or acidity external stimulus. Smart polymers ensure the release of CRISPRs under conditions which are appropriate for their function within the body and, by consequence, improve such technologies in efficacy and safety.

3. Vaccines: Polymers are important in modern vaccine development and find application in COVID-19 mRNA-based vaccines according [5]:

3.1 RNA packaging:

mRNA vaccines use the protective packaging of RNA with the help of polymers that would safely deliver the genetic material into the immune cells. It prevents the

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degradation of the genetic material while being transported inside the cell, hence assuring effectiveness with an immune response and sans the use of any viral vector.

3.2 Next-generation vaccine development:
Besides that, polymers contribute to making more stable and effective vaccines by improving the immune response and therefore decreasing the dosages needed. In such a way, safer and more effective vaccination is possible for various diseases.

4. Application of Polymers in Regenerative Medicine and Tissue Engineering: As of lately, biodegradable polymers have found their applications in developing the scaffold in the process like the regeneration of medicine and body tissues. The polymer provided support media which enhances growth formation; simultaneously degrade once it has accomplished their desired job with no toxic presentation within the body according [6]:

4.1 Polymeric Tissue Structures
Biodegradable polymer three-dimensional structures have been fabricated for the growth of tissues such as bone, cartilage, and skin tissues. These structures give a strong foundation to the growth of damaged tissues.

4.2 Practical Applications
Tissue engineering treats diseases and injuries that involve tissue regeneration, such as large wounds or tissue loss due to chronic diseases, by the application of polymers. Advanced polymers make the replacement of damaged tissues possible or support natural tissue regeneration.

5. Polymers in Biosensing Systems: Polymers are also used in the fabrication of biosensors that help in the detection of biological molecules such as proteins and nucleic acids or biomarkers of diseases. Polymers improve the sensitivity and accuracy of these devices according to [7] include medical diagnosis, polymers enable the early detection of a disease through accurate and fast sensors that detect important biological molecules. These devices can be used in the diagnosis of cancer or infectious diseases.

6. Chemical and Physical Properties of Polymers: The chemical and physical properties of polymers are determined by the molecular structure and method of manufacture, which affect their performance in various applications according [8] :

6.1 Chemical Properties of Polymers:
The basic building block of a polymer is often referred to as "monomer". The number and nature of these monomers affect the ultimate chemical properties in the molecule divided chemical activity that are possible by the interaction of polymers, like reacting with acid or bases and biodegradable polymers finally decompose into innocuous components; their usage involves environmental and biomedical applications.

6.2 Physical Properties of Polymers include according to [9]

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Molecular Weight: The molecular weight of polymers varies from a few thousand to millions, and this variation affects the properties of the polymer such as viscosity and stiffness

Structure: Polymers can be linear, branched, or networked, and their structure affects how the polymer reacts to heat and pressure.

Temperature: Temperature has a great effect on the physical properties of polymers.

Elasticity: This is a general property of polymers; some polymers are flexible-they can be stretched or contracted without breaking.

Previous and recent studies on the use of polymers in genetic engineering and biotechnology, some of the most important being

1. Previous studies on polymers in gene transfer: According [10] "Polymeric Nanoparticles for Gene Delivery" (2017), The study mainly deals with gene transfer using nanopolymers, whereby polymers are modified to enhance the transference of DNA into the cells. The role of polymers such as PEI (Polyethyleneimine) and PLGA (Poly(lactic-co-glycolic acid)) has been realized in developing safer and more effective gene transfer systems. And [11] Gene Delivery Using Polymers: Current and Future Perspectives" (2019)

This article discusses the crucial role of polymers in the transfection process of gene transfer through non-viral systems, along with chemical modification in polymers to enhance transmissibility across cell membranes and reducing cytotoxicity.

Recent studies of the role of polymers in CRISPR-Cas9 gene editing:

According [12] Polymers in CRISPR/Cas9-based Gene Editing: A Review" (2020), this work is dedicated to the role that could be played by polymers in the enhancement of CRISPR-Cas9 technology efficiency. It describes how the use of polymers protects CRISPR components from degradation on the way to target cells and touches on smart polymers, which interactively influence the environment in the organism for more accurate gene editing.

About [13] Polymer-based Nanocarriers for CRISPR/Cas9 Delivery" (2023), the following review will discuss the role and utilization of nanopolymers as carriers for CRISPR/Cas9 systems, and how these might enable improvements in stability and precision within cellular gene editing.

Research regarding the use of polymers in vaccine development:

According [15] Polymeric Nanoparticles for mRNA Vaccine Delivery" (2021), in the present review, polymers will be discussed in relation to their application in the development of mRNA vaccines but, in particular, application concerning COVID-19 vaccines. Polymers can coat mRNA by shielding them during their path in cells for an effective immune system response.

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About [16] Polymeric Nanocarriers for Vaccine Delivery" (2022), the present study investigates nanopolymers as one of the vaccine delivery approaches for target cells, focusing on how these polymers contribute to improving immune response and diminishing the side effects of vaccines.

Studies on polymers in regenerative medicine and tissue engineering:
According [17] Biodegradable Polymers for Tissue Engineering Applications" (2018), the work has thrown light on the different uses of biodegradable polymers in tissue engineering, mainly on the creation of an ideal environment with the help of biodegradable polymers intra bodily for the regeneration of tissues that have been lost or damaged.

About [18] Polymer Scaffolds for Bone and Cartilage Tissue Engineering" (2021), this article presents the development of 3D polymeric scaffolds to support bone and cartilage tissue growth. It illustrates the importance of biodegradable polymers as an effective alternative to synthetic grafts in regenerative medicine.

Studies on Polymers in Biosensing:
According [19] Polymer-Based Biosensors for Disease Detection" (2022), this study will highlight the development of biosensors that are used in the detection of biomolecules like proteins and nucleic acids using polymers. Polymers are being used to improve precision and the effectiveness of these devices in the early detection of diseases.

Applications
In a number of technological uses, polymers depend on their chemical and physical properties. The following are some of their applications include according [20,21]

Gene Transfer: Biodegradable polymers are used to make gene carriers in gene therapies.
Vaccines: Polymers have been used during vaccine development through enhancement of effective drug delivery and release.
Medical Devices: Several medical devices manufactured by using polymers include implants, surgical instruments, among others.

Conclusion:

1- Polymers greatly contribute to solving modern medical problems, acting as an effective vector of genes that enable transportation of genetic material to the target cells.

2- Medical application of the polymers would no doubt be affected by related challenges of toxicity and premature degradation.
3- Two major properties, surface charge and degradability, in polymers very effectively bias the polymer biocompatibility and their applications in medicine.

4- Polymers are of critical importance regarding protection and delivery of CRISPR-Cas9-based gene editing systems, thus improving their therapeutic potential for treatment of genetic diseases and others.

5- Polymers have contributed to the development of modern vaccines, like mRNA vaccines, through improving the immune system response and offering stability to the vaccine. They are also used in regenerative medicine in rebuilding damaged tissues.

6- Polymers contribute to the development of innovative sensors for the detection of biomolecules, hence contributing to rapid medical diagnosis and the management of diseases.

7- It insists on the need for cooperation between different scientific disciplines for the realization of such necessary innovations in the use of polymers. Continuous innovation in design and development is required for the polymers to be more effective and efficient in a wide range of applications.

Further studies are recommended in a wide range of future uses of polymers in health and medicine, for betterment in global healthcare and delivering innovative solutions to complex health problems.

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