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A Detailed Review on Biodegradable Drug Delivery Systems

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ABSTRACT
This review aims to provide a comprehensive understanding of biodegradable drug delivery systems (DDS), focusing on their types, advantages, challenges, and various applications in drug delivery, including cancer therapy, wound healing, gene therapy, and vaccine delivery. Based on the potential for controlled drug release, targeted delivery, and reduced side effects, DDS use biodegradable materials that break down into non-toxic by-products, thereby avoiding the need for surgical removal.
Keywords:biodegradable, drug delivery systems, cancer therapy, controlled drug release, targeted delivery, wound healing, gene therapy.

I. INTRODUCTION

1. Introduction

The history of biodegradable drug delivery systems (DDS) is extensive and goes back many years. The discipline developed as pharmaceutical technology advanced more broadly with the goal of enhancing therapeutic results and medication delivery. To get around the drawbacks of conventional drug delivery systems, researchers have created sophisticated materials and procedures throughout time. These developments have produced advanced biodegradable systems that can target certain tissues, regulate drug release, and improve a medicine's therapeutic index. Here is a summary of the major turning points, innovations, and contributions made to the field of biodegradable DDS development over time. As scientists and physicians realized the difficulties with the traditional drug administration techniques, such oral tablets and injections, the necessity for controlled drug delivery systems arose in the middle of the 20th century. These techniques frequently led to low bioavailability, quick drug excretion from the body, and frequent dosage requirements. In addition, adverse consequences were a major worry, particularly when medications were not administered to the right place.Drug delivery systems (DDS) optimize the release of pharmaceuticals and make sure they reach their designated site of action, hence increasing their therapeutic efficacy. Conventional drug delivery methods can lead to adverse effects, inadequate therapeutic concentrations at the target location, and fast drug removal. By delivering sustained release profiles, decreased toxicity, and the capacity to distribute medications over prolonged periods of time without the need for external removal, biodegradable drug delivery systems provide a solution. The use of biodegradable polymers, which break down into byproducts that are harmless for the body, has completely changed how we distribute drugs. By controlling medication release, these systems enhance therapeutic results and lessen adverse effects. This study will cover the numerous kinds of biodegradable DDS, their benefits, their uses in various medical specialties, and the difficulties in creating and utilizing them.

2. Different Types of Biodegradable Drug System Delivery

Biodegradable DDS may be divided into a number of groups according to the materials, drug encapsulating technique, and delivery system. The most common types include:

2.1 Biodegradable Polymers

Naturally occurring and manufactured polymers are the two main types of polymers that make up the majority of biodegradable DDS.

Natural Polymers:

- **Polysaccharides** (e.g., chitosan, alginate, and dextran):Their inherent biocompatibility and biodegradability make polysaccharides widely employed. It is possible to alter these polymers to improve their drug delivery capabilities. Crustacean shells are the source of chitosan, which has been extensively researched for tissue engineering, wound healing, and medication encapsulation.
- **Proteins** (e.g., collagen, albumin, and gelatin):Proteins are beneficial for drug

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delivery systems that need to integrate with biological tissues since they are both biocompatible and bioactive. For example, collagen finds extensive usage in wound healing applications.

- **Polypeptides and proteins**: Controlled peptide and protein medication delivery is a common usage for these. Despite their structural flexibility and biocompatibility, they need careful degradation rate control.

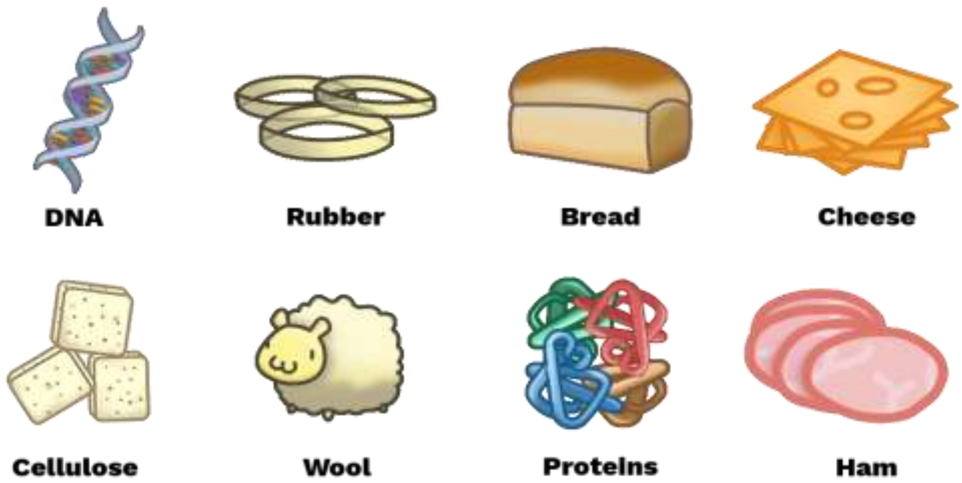

Fig. 1 Examples of Natural Polymers

Synthetic Polymers:

- **Poly(lactic acid) (PLA)** and **poly(glycolic acid) (PGA)**: It is possible to manufacture these biodegradable polyesters into films, microspheres, and nanoparticles, among other forms. The regulated degradation rates of PLA and PGA make them popular choices for medication encapsulation.
- **Poly(lactic-co-glycolic acid) (PLGA)**: This copolymer's superior biocompatibility, biodegradability, and regulated pace of decomposition make it one of the most popular biodegradable materials. Microspheres and nanoparticles are two examples of the drug delivery methods that have made use of PLGA.

Fig. 2 Examples of Synthetic Polymers

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By altering the ratio of lactic acid to glycolic acid, which directly affects the drug release profile, the pace at which synthetic polymers such as PLA and PLGA degrade may be regulated.

2.2 Microspheres and Nanoparticles

The controlled release of medications has been greatly enhanced by the widespread usage of biodegradable nanoparticles and microspheres. These particles provide a number of benefits, such as increased bioavailability, extended drug release, and tissue-specific targeting.

- **Microspheres**: Pharmaceuticals that are hydrophilic or hydrophobic are frequently encapsulated in these spherical particles, which vary in size from a few microns to several millimeters. Chitosan, PLA, and PLGA are examples of polymers that are used to create the microspheres. The encapsulated medication is progressively released when the microspheres break down after administration.

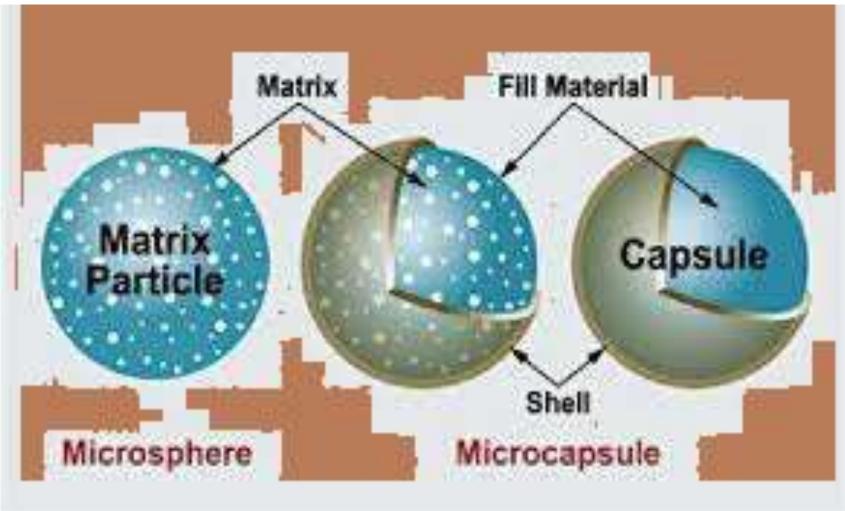

Fig. 3Microspheres

- **Nanoparticles**: Nanoparticles are utilized for targeted medicine delivery and usually have a diameter of less than 1000 nm. Their compact size enables better tissue penetration and the potential for cellular or subcellular drug delivery. Drugs can be released from nanoparticles over long periods of time or in response to certain environmental cues like temperature or pH.

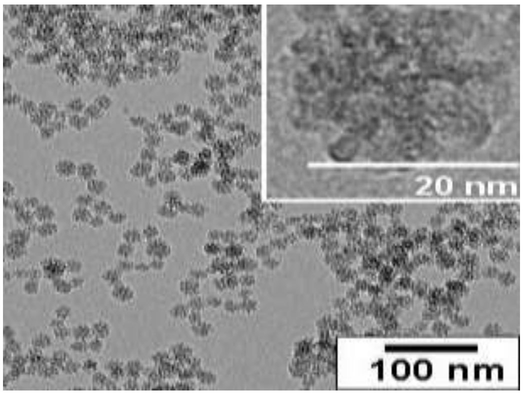

Fig.4Nanoparticles

It is possible to create nanoparticles with lipids, surfactants, and biodegradable polymers. They have been effective in encapsulating medications for gene delivery, cancer treatment, and vaccine administration.

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2.3 Hydrogels

Three-dimensional networks of hydrophilic polymers, known as hydrogels, have the capacity to absorb vast volumes of biological fluids or water. These networks are perfect for drug delivery systems that need dynamic release profiles because they swell in response to variations in temperature, pH, or ionic strength.

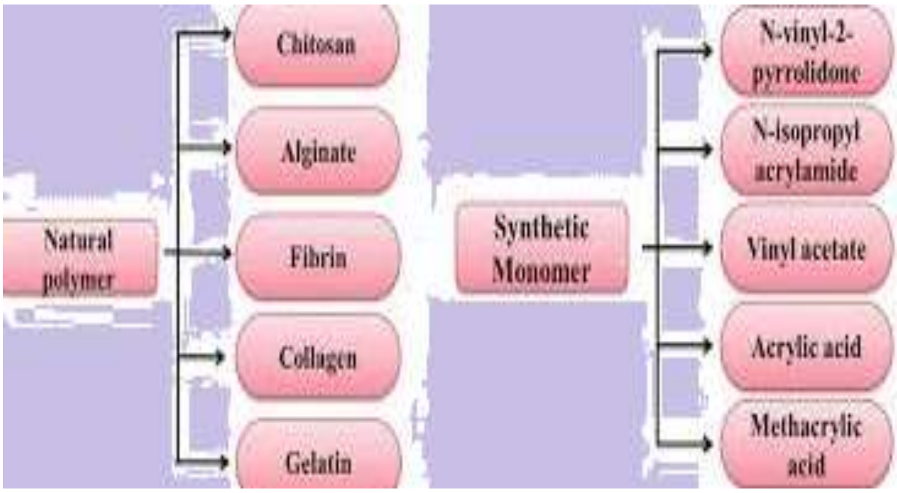

Fig.5Hydrogels

- **Natural hydrogels**: Hydrogels derived from natural polymers, including chitosan, hyaluronic acid, and alginate, are utilized in many different applications because of their superior biodegradability and biocompatibility.
- **Synthetic hydrogels**: Poly(ethylene glycol) (PEG), poly(vinyl alcohol), and poly(N-isopropylacrylamide) are examples of synthetic polymers used to make these. Synthetic hydrogels are frequently employed in tissue engineering and controlled drug release applications, and they may be designed for certain release characteristics.

Hydrogels have found application in the targeted treatment of inflammatory disorders, ocular drug delivery, and controlled drug administration in wound healing.

2.4 Liposomes and Nanoliposomes

Liposomes are lipid-based vesicles that offer a reliable delivery method for hydrophobic medications. Liposomes can provide continuous release, enhance solubility, and shield medications from deterioration.

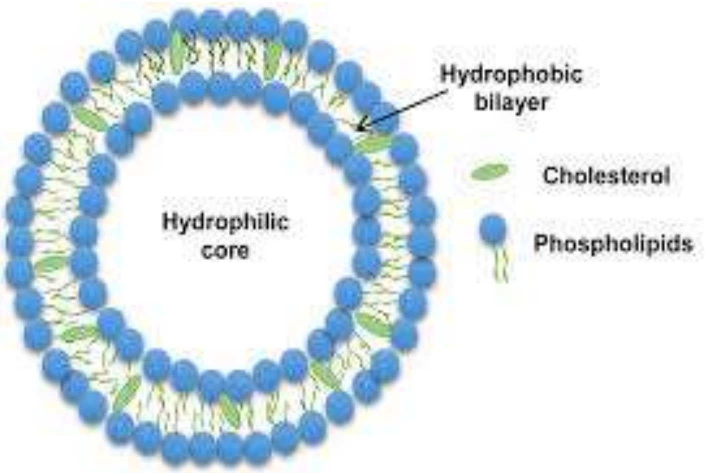

Fig.6Liposomes

- **Conventional liposomes**: These are produced from phospholipids and cholesterol, generating bilayer structures that may encapsulate both hydrophilic and hydrophobic medicines.

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Liposomes offer flexibility in drug release kinetics and are commonly employed in chemotherapy.

- **Nanoliposomes**: These are miniature variants of regular liposomes, usually with a diameter of 50–500 nm. Deeper tissue penetration and the capacity to administer medications to certain cells or tissues are two benefits of using nanoliposomes.

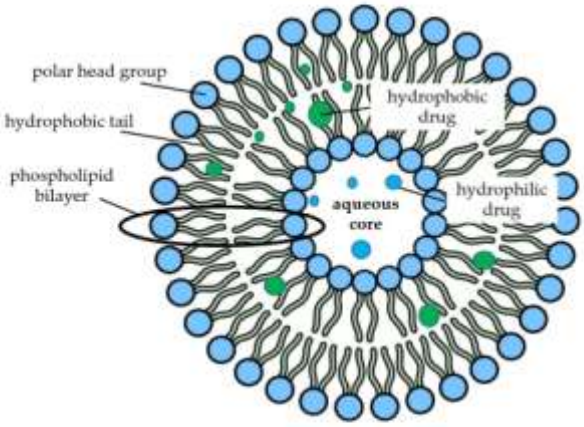

Fig.7 Nanoliposomes

Research on liposomes in drug delivery has been extensive, especially for gene therapy and cancer treatment.

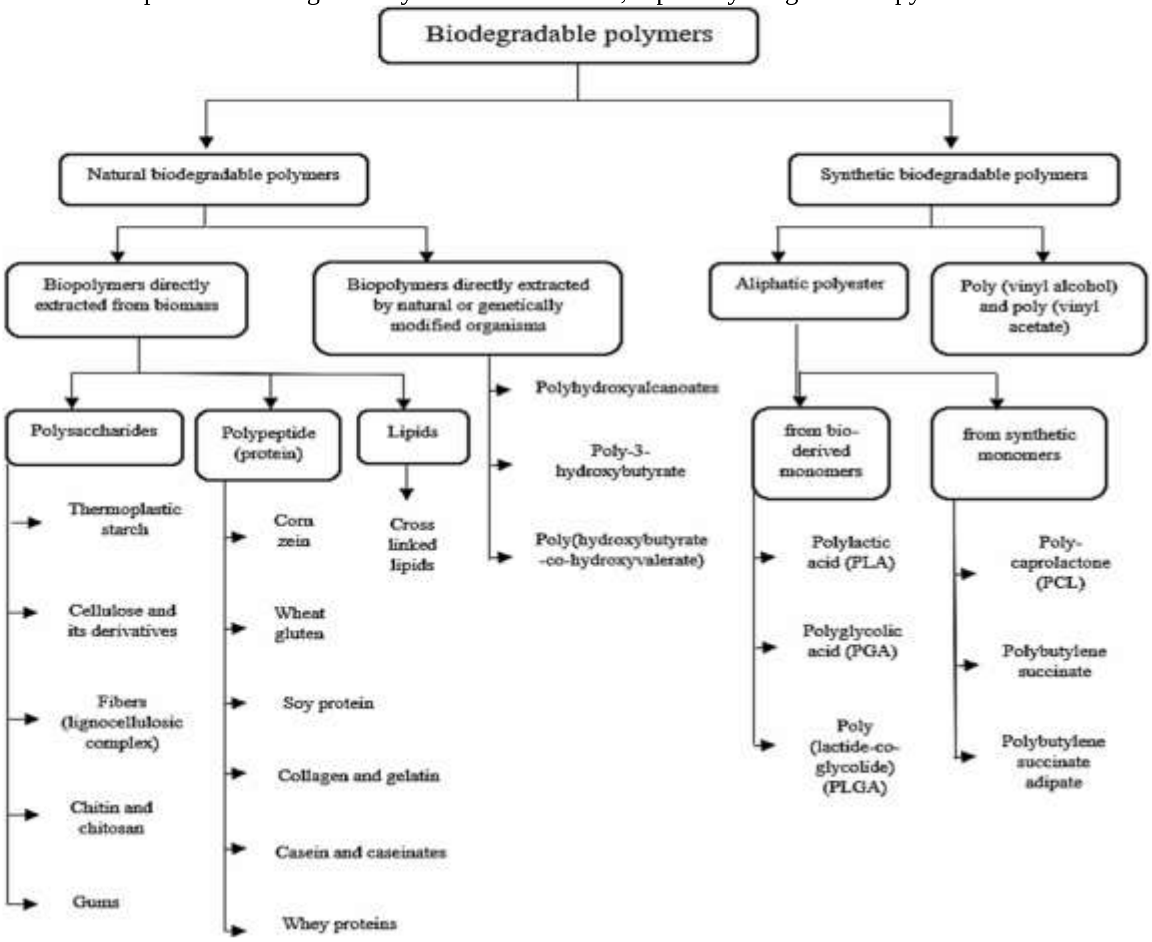

Fig. 8 Classification of Biodegradable Polymers

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3. Advantages of Biodegradable Drug Delivery Systems

Compared to conventional drug delivery methods, the usage of biodegradable DDS offers several benefits. Some of the key benefits include:

3.1 Controlled Drug Release

It is possible to create biodegradable DDS that will release medications over time at a regulated pace. By maintaining therapeutic levels of the medication in the body, this controlled release mechanism minimizes drug concentration changes and eliminates the need for frequent dosing.

In cancer treatment, for instance, PLGA-based microspheres can release chemotherapeutic drugs like doxorubicin or paclitaxel over a period of weeks or months, resulting in sustained therapeutic levels and lowering the possibility of adverse effects linked to high peak concentrations.

3.2 Targeted Delivery

Targeting certain tissues or cells is one of the main advantages of biodegradable DDS. It is possible to target particular cells, such immunological or cancer cells, with biodegradable nanoparticles and liposomes by altering their surfaces (e.g., coating with ligands or antibodies), which enhances therapeutic results while lowering off-target consequences.

For example, it is possible to create tailored nanoparticles that will attach to antigens unique to tumors, guaranteeing that the medication reaches the tumor location and minimizing harm to healthy cells.

3.3 Biocompatibility and Reduced Toxicity

When biodegradable materials are constructed correctly, they break down into simple molecules, carbon dioxide, and water, which are non-toxic metabolites. As opposed to non-biodegradable implants, this reduces the possibility of foreign materials building up in the body. Furthermore, these materials are often biocompatible, which lowers the risk of inflammation or immunological rejection.

3.4 Enhanced Patient Compliance

Biodegradable DDS can decrease the frequency of medication delivery, which can increase patient compliance. The requirement for daily dosage can be decreased by using sustained-release implants or microparticles, which can deliver medications for weeks or even months. Managing chronic diseases and patients who might struggle to follow a regular dosage regimen would benefit most from this.

3.5 Non-Invasive Nature

Biodegradable DDS decompose spontaneously within the body, negating the need for a second treatment, as contrast to standard implants that must be surgically removed. Because of its non-invasive nature, biodegradable DDS is very appealing for a variety of uses.

4. Applications of Biodegradable Drug Delivery Systems

The controlled release features and versatility of biodegradable DDS have led to its use in a variety of medical fields. The following are some of the more noteworthy applications:

4.1 Cancer Therapy

The treatment of cancer sometimes entails the use of extremely powerful chemotherapeutic medications, which have serious adverse effects because of their non-specific distribution. By increasing treatment results, lowering systemic toxicity, and delivering drugs to tumor locations precisely, biodegradable DDS—in particular, nanoparticles and microspheres—can assist in resolving these problems. Chemotherapy medications including doxorubicin, cisplatin, and paclitaxel can be encapsulated in nanoparticles like PLGA-based formulations, which provide controlled and prolonged drug release characteristics. Moreover, these systems may deliver medications precisely to cancer cells by conjugating targeting ligands, such peptides or antibodies, to the surface of nanoparticles. This maximizes efficacy while reducing harm to healthy organs.

4.2 Wound Healing

Because biodegradable DDS may carry medications like growth hormones, antibiotics, and anti-inflammatory medicines straight to the wound site, they have demonstrated considerable potential in wound healing applications. Because hydrogels may enable regulated medication release and a moist environment that promotes healing, they are especially well-suited for this use. The capacity of collagen-based drug delivery systems to facilitate tissue regeneration and accelerate wound healing through the release of collagen and growth factors has been the subject of much research.

4.3 Gene Therapy

Gene therapy is the process of correcting or changing genes linked to illnesses by delivering genetic material, such as DNA, RNA, or oligonucleotides, to specific cells. When it comes to gene delivery, biodegradable nanoparticles and liposomes provide a non-viral substitute that is safer and lowers the possibility of an immunological reaction than conventional viral vectors. Target cells have been delivered plasmid DNA, siRNA, and mRNA using PLGA and chitosan nanoparticles, which provide controlled release and improved cellular absorption. Treatments for viral infections, cancer, and genetic abnormalities have showed promise with these systems.

4.4 Vaccine Delivery

The administration of vaccines has also been investigated using biodegradable DDS, namely for the controlled and sustained distribution of adjuvants or antigens. In addition to boosting the immune response, liposomes and nanoparticles can encapsulate antigens and shield them from deterioration. PLGA nanoparticles, for example, have been utilized to administer vaccinations against cancer, influenza, and HIV because they provide improved immune activation and longer antigen release.

5. Challenges and Limitations

Although biodegradable medication delivery methods have several benefits,, there are several challenges that need to be addressed:

5.1 Control of Degradation Rates

A biodegradable material's rate of degradation can have a big effect on the medication release profile. A substance that breaks down too rapidly might release the medicine too soon, whereas one that breaks down too slowly could prevent the therapeutic effect. It is necessary to precisely tailor the materials in order to get the appropriate deterioration rate.

5.2 Toxicity of Degradation Products

Even while a lot of biodegradable compounds break down into harmless byproducts, others could produce metabolites that are harmful or inflammatory. To make sure the materials do not endanger the patient, it is crucial to thoroughly examine their degradation products.

5.3 Manufacturing Challenges

Making biodegradable DDS, particularly nanoparticles and microspheres, calls very intricate and exacting methods. These manufacturing procedures can be difficult to scale and reproduce, especially when trying to achieve high drug loading and unique release characteristics.

5.4 Limited Drug Loading Capacity

Some biodegradable DDS, especially nanoparticles, might not be able to hold large amounts of medication. For high-dose treatments, this restriction may lessen their efficacy and call for the use of higher or more frequent dosages.

6. Conclusion

Because they provide focused distribution, controlled release, and fewer adverse effects, biodegradable drug delivery devices provide a viable way to enhance medication therapy. There is a lot of promise for treating a variety of illnesses, including as cancer, genetic abnormalities, and chronic problems, by creating DDS with tunable degradation rates and release patterns. Degradation control, toxicity, and manufacturing issues still exist, nevertheless. The therapeutic uses of biodegradable DDS will probably grow as long as materials science and drug delivery technologies continue to progress.

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