American Journal of Pharmaceutics
australiansciencejournals.com/pharmaceutics
E-ISSN: 2689-0259
VOL 05 ISSUE 01 2024

The Use of Cyclodextrins in Pharmaceutical Formulations

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Abstract: *Cyclodextrins (CDs) are cyclic oligosaccharides known for their ability to form inclusion complexes with a wide range of pharmaceutical compounds. This property has led to their widespread use in pharmaceutical formulations to improve the solubility, stability, and bioavailability of poorly water-soluble drugs. Cyclodextrins have been used in oral, parenteral, and topical drug delivery systems, facilitating the development of novel drug formulations. This article explores the role of cyclodextrins in pharmaceutical formulations, including their mechanism of action, types, advantages, and applications in the enhancement of drug delivery. The review also discusses the challenges and future directions for cyclodextrin-based formulations in pharmaceutical sciences.*

Keywords: *Cyclodextrins, drug delivery, solubility enhancement, pharmaceutical formulations, inclusion complexes, bioavailability, drug stability, pharmaceutical applications*

Introduction:

Cyclodextrins (CDs) are naturally occurring cyclic oligosaccharides composed of glucose units linked by α-1,4 glycosidic bonds. These molecules have a unique molecular structure that enables them to encapsulate hydrophobic drugs in their hydrophobic cavity, forming inclusion complexes. This ability makes CDs highly effective in enhancing the solubility and stability of poorly water-soluble drugs. In pharmaceutical formulations, cyclodextrins are used to increase the bioavailability of drugs, reduce side effects, and improve the overall effectiveness of therapeutic agents. Over the years, various forms of cyclodextrins have been developed to cater to different pharmaceutical applications, including oral, parenteral, and topical drug delivery.

2. Types of Cyclodextrins

Cyclodextrins (CDs) are cyclic oligosaccharides made up of glucose units linked by α-1,4-glycosidic bonds. They are classified based on the number of glucose units in their structure, which determines the size of their hydrophobic cavity. The ability of CDs to form inclusion complexes with hydrophobic drugs is key to enhancing drug solubility, stability, and bioavailability. Here, we explore the different types of cyclodextrins, their properties, and applications in pharmaceutical formulations.

α-Cyclodextrins

Structure and Properties:

α-Cyclodextrins consist of six glucose units, forming a relatively small, truncated cone-shaped cavity. This small cavity size limits the types of drug molecules that can be encapsulated effectively. The outer surface of α-cyclodextrins is hydrophilic, which enhances their solubility in aqueous environments, while the internal cavity is hydrophobic, providing the necessary conditions to solvate hydrophobic compounds.

Applications in Pharmaceutical Formulations:

α-Cyclodextrins are primarily used for small-molecule drugs that require a smaller encapsulation space. Due to their relatively small cavity size, they are most effective for encapsulating low-molecular-weight drugs and compounds.

They are commonly employed in **oral formulations** where the drug needs to be solubilized to enhance bioavailability.

They are also utilized in **topical formulations** for enhancing the penetration of hydrophobic drugs through the skin.

Limitations:

The primary limitation of α-cyclodextrins is their smaller cavity, which restricts their ability to encapsulate larger or more complex drug molecules. This limits their application to drugs with lower molecular weights.

β-Cyclodextrins

Structure and Properties:

β-Cyclodextrins consist of seven glucose units and have a larger cavity compared to α-cyclodextrins. This allows for the encapsulation of a broader range of hydrophobic molecules, making them the most widely used form of cyclodextrins in pharmaceutical formulations.

The larger cavity size allows β-cyclodextrins to encapsulate a variety of pharmaceutical compounds, including many hydrophobic drugs, peptides, and proteins. β-Cyclodextrins are also known for their excellent solubility in water, which enhances their performance in aqueous-based formulations.

Applications in Pharmaceutical Formulations:

β-Cyclodextrins are commonly used in both **oral and parenteral drug delivery systems**. They improve the solubility and stability of poorly water-soluble drugs and enable controlled release profiles.

They are used in **intravenous formulations** to solubilize hydrophobic drugs that would otherwise require toxic organic solvents.

β-Cyclodextrins also play a role in **nasal and ocular drug delivery**, where they improve the solubility of drugs administered through the nasal and ocular routes.

Advantages:

The larger cavity of β-cyclodextrins makes them more versatile, allowing them to accommodate a broader range of drug molecules compared to α-cyclodextrins.

Their ability to enhance the solubility and bioavailability of a wide variety of pharmaceutical agents makes them ideal candidates for many drug delivery applications.

γ-Cyclodextrins

Structure and Properties:

γ-Cyclodextrins consist of eight glucose units, forming a cavity that is even larger than that of β-cyclodextrins. This larger cavity size allows γ-cyclodextrins to encapsulate larger drug molecules, particularly those with higher molecular weights.

γ-Cyclodextrins have a unique ability to enhance the solubility and stability of large, poorly soluble compounds, such as high-molecular-weight peptides, proteins, and certain hydrophobic organic molecules.

Applications in Pharmaceutical Formulations:

γ-Cyclodextrins are particularly beneficial for the formulation of **large molecules** like monoclonal antibodies, proteins, and other biopharmaceuticals. Their ability to encapsulate large, hydrophobic molecules improves the solubility and stability of these drugs, making them more suitable for oral or injectable delivery.

They are also used in **drug formulations for sustained release**, where the encapsulation of larger molecules can help achieve controlled and prolonged drug delivery.

Gene delivery systems and **immunotherapeutic agents** benefit from γ-cyclodextrins, which aid in improving their solubility and stability while minimizing degradation.

Limitations:

Despite their ability to accommodate larger molecules, γ-cyclodextrins are less commonly used due to their higher production costs and limited availability compared to α- and β-cyclodextrins.

The larger cavity size can also make γ-cyclodextrins less efficient at encapsulating smaller molecules, limiting their versatility.

Modified Cyclodextrins

Structure and Properties:

Modified cyclodextrins are chemically altered forms of the natural CDs (α, β, or γ), where functional groups are introduced or replaced to improve their properties. Common modifications include the introduction of hydrophobic or hydrophilic groups, which enhance solubility, stability, or safety profiles.

Common modifications involve:

Substitution of hydroxyl groups to enhance stability or improve solubility in specific solvents.

Derivatives with alkyl or hydroxypropyl groups that increase the aqueous solubility of cyclodextrins, making them suitable for a wider range of drug formulations.

Applications in Pharmaceutical Formulations:

Modified cyclodextrins are used in a variety of formulations to address the limitations of native CDs, such as poor solubility or toxicity concerns. For instance, **hydroxypropyl-β-cyclodextrin (HPβCD)** is commonly used in parenteral drug formulations due to its ability to solubilize hydrophobic drugs while minimizing toxicity.

Modified CDs are used in **complexation with large molecules**, improving the solubility and stability of sensitive biologics, proteins, and vaccines.

These modified versions also enable **targeted drug delivery**, where the modified cyclodextrins can be functionalized to target specific tissues or cells in the body.

Advantages:

Modified cyclodextrins can significantly improve the solubility, stability, and bioavailability of poorly soluble drugs.

They offer greater flexibility in pharmaceutical formulations, especially for challenging drug candidates that require specific solubility profiles or enhanced stability.

Challenges:

The increased complexity and cost of producing modified cyclodextrins can be a barrier to their widespread use.

Regulatory hurdles may arise due to the need for extensive safety and toxicity testing for new modified forms of cyclodextrins. Cyclodextrins, in their various forms, are versatile and powerful tools in pharmaceutical formulations, helping to enhance the solubility, stability, and bioavailability of a wide range of drugs. The different types of cyclodextrins—α, β, and γ—offer unique advantages depending on the size of the drug molecule being encapsulated. Modified cyclodextrins provide further opportunities to tailor the properties of cyclodextrins to meet specific pharmaceutical needs. However, challenges related to cost, toxicity, and regulatory approval remain. As research continues to explore new modifications and applications, cyclodextrins will likely play an increasingly important role in the development of novel drug delivery systems.

Mechanism of Action

Inclusion Complex Formation:

Cyclodextrins possess a unique structure with a hydrophobic interior and a hydrophilic exterior. The hydrophobic cavity can encapsulate the hydrophobic portion of drug molecules, while the hydrophilic exterior interacts with the surrounding aqueous environment.

Drugs that are poorly soluble in water are often encapsulated inside the cavity, while their hydrophilic portions may interact with the exterior, allowing the compound to remain in solution.

Enhanced Solubility:

One of the most significant benefits of cyclodextrin inclusion complexes is the improved solubility of hydrophobic drugs. By encapsulating the hydrophobic drug inside the cyclodextrin cavity, the solubility of the drug in water is significantly increased, which is essential for oral and injectable drug formulations.

Stabilization and Protection:

Cyclodextrins help protect drugs from environmental factors like heat, light, and oxygen, which can lead to degradation. The inclusion complex acts as a protective barrier that helps maintain the chemical stability of the drug over time.

Controlled Drug Release:

Cyclodextrins can also influence the release rate of drugs. By modifying the structure of the inclusion complex or the concentration of cyclodextrin, the release profile of the drug can be controlled. This controlled release can be essential for drugs requiring sustained or prolonged action.

For instance, cyclodextrins may slow down the dissolution of a drug in the gastrointestinal tract, providing sustained therapeutic effects.

Improved Bioavailability:

Since many poorly water-soluble drugs have limited bioavailability when taken orally, cyclodextrins improve this aspect by enhancing solubility and dissolution rates, leading to better absorption in the gastrointestinal tract. This is particularly important for drugs with low oral bioavailability, such as antifungal, anticancer, and anti-inflammatory agents.

Types of Cyclodextrins and Their Applications:

α-Cyclodextrins:

Comprising six glucose units, these are typically used for smaller drug molecules and are particularly useful in forming inclusion complexes with lipophilic drugs that do not require a large cavity.

β-Cyclodextrins:

With seven glucose units, these cyclodextrins offer a larger cavity, making them suitable for encapsulating a broader range of drug molecules. They are the most commonly used in pharmaceutical formulations due to their ability to accommodate a variety of drug structures.

γ-Cyclodextrins:

These have eight glucose units and offer an even larger cavity, which is ideal for larger drug molecules or those with higher molecular weights.

Modified Cyclodextrins:

To overcome the limitations of natural cyclodextrins, such as poor water solubility or insufficient inclusion capacity, chemically modified cyclodextrins have been developed. These modifications may include the substitution of hydroxyl groups with other functional groups to improve solubility, enhance stability, or increase the inclusion capacity.

Applications in Pharmaceutical Formulations

Cyclodextrins (CDs) play a crucial role in various pharmaceutical formulations, enhancing the solubility, stability, and bioavailability of hydrophobic drugs. Their ability to form inclusion complexes with drugs significantly improves the delivery and therapeutic outcomes of poorly soluble or unstable compounds. The following sections highlight the key applications of cyclodextrins in oral, parenteral, and topical drug delivery systems.

Oral Drug Delivery

Cyclodextrins are widely used in **oral drug formulations** to improve the solubility and bioavailability of drugs that are poorly soluble in water. Hydrophobic drugs often exhibit low dissolution rates when administered orally, resulting in limited absorption in the gastrointestinal tract and reduced therapeutic efficacy. Cyclodextrins address this issue by encapsulating the hydrophobic drugs in their hydrophobic cavity, thereby enhancing their solubility in aqueous environments and facilitating their absorption.

Key Applications in Oral Drug Delivery:

Tablets and Capsules: Cyclodextrins are commonly incorporated into solid oral dosage forms, such as tablets and capsules, to improve the dissolution rate of poorly water-soluble drugs. By forming inclusion complexes, cyclodextrins help release the drug more efficiently upon ingestion, ensuring better absorption in the digestive tract.

Suspensions: Cyclodextrins can be used in suspensions to enhance the solubility of drugs that are not easily dissolved in water. The inclusion complexes formed between cyclodextrins and hydrophobic drugs enable the suspension to remain stable, improving the drug's bioavailability.

Controlled Release Systems: Cyclodextrins are also employed in **controlled-release formulations**, where they allow for the gradual release of the drug over time. This helps maintain therapeutic drug levels in the bloodstream, improving the overall efficacy and reducing the frequency of administration.

Benefits:

Enhanced solubility and bioavailability of poorly soluble drugs.

Faster drug absorption due to improved dissolution rates.

Better patient compliance with more efficient drug delivery and controlled release.

Parenteral Drug Delivery

In **parenteral drug delivery**, cyclodextrins are used to solubilize hydrophobic drugs that would otherwise be poorly soluble in aqueous media. This is especially important for injectable drug formulations, such as intravenous (IV) injections, where solubility is crucial to achieving effective dosing. Cyclodextrin-based formulations help improve the solubility of hydrophobic drugs, reducing the need for toxic organic solvents that are often used to dissolve such compounds.

Key Applications in Parenteral Drug Delivery:

Intravenous (IV) Injections: Cyclodextrins are commonly used in IV formulations to solubilize hydrophobic drugs, allowing them to be administered intravenously without the use of harmful solvents. For example, **hydroxypropyl-β-cyclodextrin (HPβCD)** is widely used in parenteral formulations for drugs like **amphotericin B** and **paclitaxel**, improving their solubility and stability.

Injectable Suspensions: Cyclodextrins are used to formulate injectable suspensions for drugs that require slow release or sustained therapeutic effects. The inclusion of cyclodextrins ensures the drug is adequately solubilized, facilitating its safe administration.

Targeted Drug Delivery: Cyclodextrins can also be used in **targeted drug delivery systems**, where they help to encapsulate drugs that are directed to specific sites in the body. This helps reduce side effects and improve the therapeutic efficacy of drugs, especially in cancer treatment.

Benefits:

Improved solubility of hydrophobic drugs in aqueous environments.

Reduced use of toxic solvents in injectable formulations.

Enhanced drug stability, leading to improved shelf-life and efficacy of injectable drugs.

Topical Drug Delivery

Cyclodextrins are increasingly used in **topical drug delivery** systems to improve the penetration of drugs through the skin.

Many drugs, especially hydrophobic compounds, face difficulties in penetrating the skin barrier, which limits their effectiveness when applied topically. Cyclodextrins address this challenge by forming inclusion complexes with drugs, enhancing their solubility in the skin's lipid-rich environment and promoting better absorption into deeper skin layers.

Key Applications in Topical Drug Delivery:

Creams and Ointments: Cyclodextrins are incorporated into topical formulations like creams and ointments to enhance the delivery of hydrophobic drugs to the skin. The inclusion complex formed with cyclodextrins allows for controlled release, improving the drug's therapeutic efficacy and reducing skin irritation.

Transdermal Patches: Cyclodextrins are used in transdermal patches to facilitate the controlled release of drugs over extended periods. This application is particularly useful for drugs that require continuous delivery, such as **hormonal therapies** and **pain management drugs**.

Cosmetic and Dermatological Products: Cyclodextrins are also found in cosmetic and dermatological products, where they help improve the skin penetration of active ingredients. They are used in formulations designed to treat skin conditions such as acne, eczema, and psoriasis.

Benefits:

Enhanced skin penetration of hydrophobic drugs.

Controlled drug release, reducing side effects and improving therapeutic efficacy.

Reduced irritation and enhanced safety profile for topical formulations. Cyclodextrins have found widespread applications in pharmaceutical formulations due to their unique ability to enhance the solubility, stability, and bioavailability of poorly water-soluble drugs. They play a crucial role in **oral**, **parenteral**, and **topical drug delivery** systems, enabling the effective administration of hydrophobic drugs across various routes of administration. By forming inclusion complexes, cyclodextrins improve drug absorption, ensure controlled release, and reduce side effects, ultimately enhancing patient compliance and therapeutic outcomes. Continued research and development will further expand the applications of cyclodextrins in pharmaceutical formulations, making them a key component of modern drug delivery systems.

Challenges in Cyclodextrin Use

While cyclodextrins (CDs) offer several advantages in drug delivery, their use in pharmaceutical formulations is not without challenges. These include toxicity concerns, stability issues, and regulatory hurdles.

Toxicity and Safety Concerns

Cyclodextrins are generally regarded as safe, with many types, including β-cyclodextrins, being used in a wide range of applications, including food and pharmaceuticals. However, **toxicity** remains a key concern, particularly at higher concentrations.

Nephrotoxicity: β-Cyclodextrins and their derivatives have been associated with nephrotoxicity, particularly when used at elevated doses. The mechanism behind this toxicity is thought to involve the accumulation of the cyclodextrin complex in kidney tissues, leading to potential kidney damage. This can be a significant concern in drug formulations, especially when the drugs require high cyclodextrin concentrations for solubility enhancement.

Mitigation Strategies: To address these safety concerns, research is being conducted to develop **safer modifications** of cyclodextrins. This includes altering the structure of cyclodextrins to reduce their potential nephrotoxic effects or using **controlled-release formulations** to minimize the systemic exposure to cyclodextrins. Additionally, **alternative cyclodextrins**, such as γ-cyclodextrins or cyclodextrin derivatives with modified side chains, are being explored to improve safety profiles.

5.2 Stability of Cyclodextrin Complexes

The **stability** of cyclodextrin-drug complexes is a crucial factor in ensuring the efficacy of cyclodextrin-based drug formulations. Several factors can influence the stability of these complexes:

Temperature: High temperatures can destabilize the inclusion complex by disrupting the weak interactions between the cyclodextrin and the drug. This can lead to the release of the drug before it reaches the intended site of action, compromising therapeutic outcomes.

pH: The solubility and stability of cyclodextrin complexes can also be affected by the pH of the formulation. Cyclodextrins tend to form more stable complexes at certain pH ranges, while at extreme pH levels, the complex may dissociate, reducing the effectiveness of the drug delivery system.

Other Excipients: The presence of other excipients, such as preservatives, stabilizers, or co-solvents, can interact with cyclodextrins, affecting the stability of the complex. These interactions need to be carefully studied to avoid destabilizing the drug-cyclodextrin complex during formulation.

Maintaining Stability: To ensure stability, controlled conditions during the storage of cyclodextrin-based formulations are essential. It is also important to optimize the formulation to ensure that the complex remains intact throughout its shelf life and under physiological conditions.

Regulatory Challenges

The use of cyclodextrins in drug formulations is subject to **regulatory scrutiny** to ensure the safety, efficacy, and quality of the final product.

Safety and Efficacy Testing: For cyclodextrin-based formulations to receive approval, extensive **preclinical and clinical testing** is required to evaluate both the safety and efficacy of the product. This testing ensures that the drug will deliver the desired therapeutic effect without causing harm to the patient.

Modified Cyclodextrins: The introduction of **modified cyclodextrins** further complicates the regulatory approval process. Modifications can alter the physicochemical properties of cyclodextrins, which may impact their safety profile and efficacy. This necessitates additional safety data, including **toxicity studies**, to demonstrate that the modified cyclodextrins are safe for human use.

Regulatory Guidelines: Regulatory agencies, such as the **U.S. Food and Drug Administration (FDA)** or the **European Medicines Agency (EMA)**, have stringent guidelines for the approval of new drug formulations. These guidelines include comprehensive evaluations of **drug delivery systems** that use cyclodextrins, including testing for **bioavailability**, **toxicity**, and **long-term stability**. The approval process can be time-consuming and costly, making it a significant barrier to the rapid commercialization of cyclodextrin-based formulations. While cyclodextrins offer numerous benefits in pharmaceutical formulations, including enhanced solubility and bioavailability, there are significant challenges to their use. These include concerns regarding toxicity, stability of drug-cyclodextrin complexes, and the regulatory hurdles associated with the approval of modified cyclodextrins. Ongoing research and development efforts aim to address these challenges, but careful formulation and safety testing are essential to ensuring the success of cyclodextrin-based drugs in clinical practice.

Future Directions

The future of cyclodextrins (CDs) in pharmaceutical formulations holds significant promise for advancing drug delivery systems. While cyclodextrins have already demonstrated great potential in enhancing solubility, stability, and bioavailability, ongoing research and development are focused on overcoming existing limitations and expanding their applications in a variety of therapeutic areas. The following research directions highlight some of the most promising developments in the field of cyclodextrin-based drug formulations.

Improved Cyclodextrin Derivatives

The development of **modified cyclodextrins** is expected to address some of the challenges associated with native cyclodextrins, such as poor solubility, toxicity, and limited encapsulation capabilities. Researchers are working on creating **new derivatives** that exhibit **enhanced solubilizing** and **stabilizing properties**, allowing cyclodextrins to better interact with a broader range of pharmaceutical compounds.

Research Directions:

Hydroxypropylation and **methylation** of cyclodextrins are key modifications aimed at improving their water solubility.

The **introduction of charged functional groups** can enable cyclodextrins to interact more effectively with hydrophobic drugs, improving encapsulation efficiency.

The development of **biodegradable** and **non-toxic cyclodextrin derivatives** is a crucial focus to improve their safety profile in pharmaceutical applications.

Applications:

Enhanced derivatives can be used for **oral**, **topical**, and **parenteral drug formulations**, particularly for drugs that require solubilization in aqueous systems.

These improvements would also enable the development of **longer-lasting** formulations that provide **sustained drug release** with minimal side effects.

Targeted Drug Delivery Systems

One of the most exciting future directions for cyclodextrins is their integration into **targeted drug delivery systems**. Cyclodextrins can be used to release drugs at **specific sites** within the body, improving therapeutic outcomes while minimizing systemic side effects. By functionalizing cyclodextrins with targeting ligands or encapsulating them in nanoparticles, it is possible to achieve **site-specific drug delivery**.

Research Directions:

Functionalization of cyclodextrins with ligands that target specific receptors on cells or tissues, such as cancer cells, for **targeted drug delivery**.

Incorporating cyclodextrins into **nanoparticles**, **liposomes**, or **microspheres** to form nanomedicines capable of delivering drugs directly to specific sites.

Stimuli-responsive systems, where cyclodextrins release their drug payload in response to environmental factors like pH, temperature, or light, further improving the precision of drug delivery.

Applications:

Cancer therapies: Targeted drug delivery using cyclodextrins could help direct chemotherapeutic agents to cancerous tissues, reducing the toxicity to healthy cells.

Gene therapies: Cyclodextrins could be used to deliver genetic material specifically to diseased cells, improving the success rate of gene therapies.

Incorporation of Cyclodextrins in Nanomedicines

The use of **cyclodextrins in nanomedicines** has emerged as a promising approach for improving the stability, solubility, and therapeutic efficacy of **anticancer drugs** and other **high-potency therapies**. Nanomedicines, such as **nanoparticles**, **liposomes**, and **polymeric micelles**, can be used in conjunction with cyclodextrins to enhance the bioavailability of poorly soluble drugs while providing controlled and sustained drug release.

Research Directions:

Developing **cyclodextrin-based nanoparticles** for the delivery of anticancer drugs, particularly those that are hydrophobic and prone to degradation.

Utilizing cyclodextrins to **encapsulate biologics** like proteins, monoclonal antibodies, and gene therapies, enhancing their stability and protecting them from enzymatic degradation.

Exploring the use of **cyclodextrin-loaded liposomes** to achieve targeted drug delivery with minimal side effects.

Applications:

Cancer treatment: Cyclodextrin-based nanomedicines can encapsulate chemotherapeutic agents and target them directly to tumors, enhancing the therapeutic efficacy and reducing the systemic toxicity of chemotherapy.

High-potency drug formulations: Cyclodextrins can be used to stabilize high-potency drugs, such as biologics and vaccines, ensuring they remain effective during storage and transportation.

Cyclodextrin-Based Formulations for Chronic Diseases

Cyclodextrins hold great potential in the development of formulations for **chronic diseases**, such as **diabetes**, **cardiovascular diseases**, and **neurological disorders**. Many of these diseases require long-term treatment with drugs that often have poor solubility or stability. Cyclodextrins can improve the delivery and effectiveness of drugs used in chronic disease management.

Research Directions:

Formulations for diabetes: Cyclodextrins can improve the solubility and bioavailability of oral antidiabetic drugs such as **glibenclamide**, **metformin**, and **insulin**.

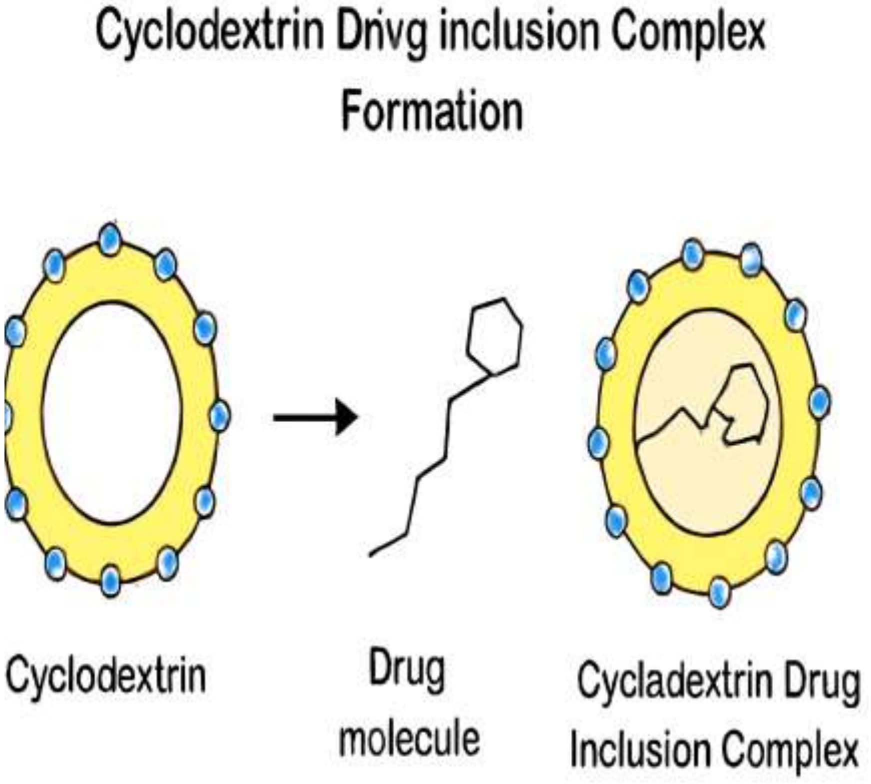
Cardiovascular drugs: Cyclodextrin-based formulations can enhance the solubility and stability of drugs like **statins**, **beta-blockers**, and **anticoagulants**, improving their long-term effectiveness in managing heart disease.

Neurological disorders: Cyclodextrins can be used in drug formulations for **neurodegenerative diseases** like Alzheimer's or Parkinson's, enhancing the delivery of neuroprotective agents to the brain.

Applications:

Diabetes: Cyclodextrin-based systems could be used to improve the oral bioavailability of insulin and other antidiabetic agents, offering more effective and convenient treatment options.

Cardiovascular treatments: By improving the solubility and stability of cardiovascular drugs, cyclodextrins could help reduce the frequency of dosing and improve patient compliance. The future of cyclodextrins in pharmaceutical formulations is bright, with numerous promising research directions focused on enhancing drug delivery systems. Improvements in cyclodextrin derivatives, the development of targeted drug delivery systems, incorporation into nanomedicines, and the treatment of chronic diseases will all contribute to expanding the utility of cyclodextrins in modern therapeutics. As the understanding of cyclodextrin chemistry and applications deepens, it is likely that cyclodextrins will continue to play a key role in advancing the effectiveness, safety, and patient compliance of pharmaceutical treatments



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Summary

Cyclodextrins have revolutionized the formulation of poorly soluble drugs, offering solutions to enhance solubility, stability, and bioavailability. Their versatility makes them ideal candidates for a wide range of pharmaceutical applications, including oral, parenteral, and topical drug delivery. Despite some challenges, such as toxicity concerns and regulatory hurdles, cyclodextrin-based drug formulations hold significant promise in improving the therapeutic outcomes of many drugs. Ongoing research and innovation in cyclodextrin chemistry are expected to further expand their use in the pharmaceutical industry.

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