2026 Volume: 02 Issue: 04 www.ijrpa.com ISSN 2456-9995 Review Article

International Journal Research Publication Analysis

Page: 01-17

THERAPEUTIC POTENTIAL OF CYCLODEXTRINS BEYOND THEIR CONVENTIONAL USE AS EXCIPIENTS

Amrita Bhattacharya*, Anand Anand, Anand Raj, Kamal Singh Bani, Dr. Nakul Gupta

IIMT College of Pharmacy, Greater Noida, G.B. Nagar, Uttar Pradesh.

Article Received: 19 March 2026
Article Revised: 09 April 2026
Published on: 29 April 2026

***Corresponding Author: Amrita Bhattacharya**
IIMT College of Pharmacy, Greater Noida, G.B. Nagar, Uttar Pradesh.
DOI: https://doi-doi.org/101555/ijrpa.8416

ABSTRACT

Cyclodextrins (CDs) are cyclic oligosaccharides widely used in pharmaceutical formulations as excipients to enhance the solubility, stability, and bioavailability of poorly water-soluble drugs through inclusion complex formation. Traditionally regarded as pharmacologically inert, cyclodextrins have recently attracted significant attention for their intrinsic therapeutic activities, positioning them as active pharmaceutical agents rather than merely formulation aids. Accumulating evidence indicates that both native and chemically modified cyclodextrins exhibit direct biological effects, including cholesterol sequestration, modulation of lipid metabolism, anti-inflammatory and antiviral activities, and interaction with cellular membranes. Notably, β-cyclodextrin derivatives such as hydroxypropyl-β-cyclodextrin and methyl-β-cyclodextrin have demonstrated therapeutic potential in the management of lipid storage disorders, neurodegenerative diseases, atherosclerosis, cancer, and viral infections by influencing membrane integrity and cellular signaling pathways. Furthermore, cyclodextrins are being explored as active components in gene delivery systems, antimicrobial therapies, and detoxification strategies. These emerging applications challenge the conventional perception of cyclodextrins as inert excipients and highlight their versatility as multifunctional therapeutic agents. This review discusses recent advances in cyclodextrin-based therapeutics, elucidates their mechanisms of action, and addresses key challenges related to safety, selectivity, and clinical translation.

KEYWORDS: Cyclodextrins; Active therapeutic agents; Drug delivery; Cholesterol modulation; Pharmaceutical excipients; Cyclodextrin derivatives.

INTRODUCTION

Chronic diseases remain the main cause of mortality across the globe. According to the World Health Organization, non-communicable diseases such as cancer, diabetes, hypertension, stroke, chronic respiratory diseases, Alzheimer's disease, and renal diseases cause over 60% of the total mortality rate, with the remaining percentage resulting from infectious diseases and neonatal diseases[**1**] Even though significant progress has been made in the synthesis of synthetic drugs, there remains a significant problem in the search for effective cures for diseases. In this regard, the search for effective and efficient treatment methods remains the main focus in the search for drugs.

Medicinal plants have always played a great role in the practice of health care and have always been of significant importance. A large percentage of the world's population depends on these plants for their medication. In the modern practice of drug discovery, there is an increasing trend towards the use of natural sources to obtain pure compounds that are effective and reliable. Among these compounds is the secondary metabolite triterpenes, which have always been of great interest due to their diverse pharmacological activities such as anti-tumor, anti-inflammatory, anti-viral, and cardio-protective activities. However, they have also been found to possess undesirable properties such as poor aqueous solubility and pharmacokinetic Cyclodextrins belonging to a class of starch family cyclic oligosaccharide compounds, have been recognized as potent agents for overcoming the limitations of the techniques mentioned above. Even though cyclodextrin use was first recorded in the late 1800s, the potential of these compounds as potent agents was only realized in the second half of the twentieth century. Up to now, cyclodextrins have been used as potent agents to enhance the solubility of poorly soluble active pharmaceutical ingredients, since these compounds can uniquely form a noncovalent complex with lipophilic compounds due to the presence of both hydrophobic and hydrophilic surfaces of the compound.[2,3] The image of cyclodextrins has changed dramatically during the last few just being passive carriers, more and more studies are showing that these molecules can also have a biological activity of their own. One of such activities can be the modulation of lipid rafts in the cell membrane that has broadened their use from simple drug delivery systems to active drug therapy Some of the latest discussions among scientists, for example in the journal Pharmaceuticals, have highlighted the boom of cyclodextrins as active pharmaceutical ingredients in the treatment of cholesterol modulation, rare diseases, viral infections, and immunology .besides that, better chemical modification of the compounds, which involve methylation, hydroxy propylation, and sulfobutylether substitution, among others, have led to more soluble, safer, and pharmacologically more active derivatives of CDs. Besides that, the compounds' ability to form inclusion complexes has been significantly improved, which has resulted in even greater interaction of the compounds with the biological membranes and receptors. Hence, cyclodextrins show great promise in the delivery of vaccines, gene therapy, oncology, neurodegenerative diseases, detoxification, and immunology.

From the arguments outlined above, it is clear that cyclodextrins could play a major role in the design of new therapeutic approaches that merge the advantages of natural product drugs with drug delivery technology. Moreover, the fact that they can be exploited both as drug delivery systems and as therapeutic agents implies that they can also be used for the development of novel therapeutic approaches[4]

CYCLODEXTRIN MECHANISM OF ACTION

"Cyclodextrins (CDs) are natural, sugar, based molecules consisting of 6, 7, or 8 glucose units arranged in a ring. These are called, , and, cyclodextrins based on the number of glucose units they contain. The most fascinating aspect of CDs is their structure. The outside of the CD loves water (lipophobic)while the inside has a small cavity that doesn't like water (lipophilic). A CD is like a small cone with a 'holding space' inside for another molecule."[5]

1.Inclusion Complex Formation (Drug Encapsulation)

Inside a cyclodextrin, space opens up where certain molecules fit snug. Picture an oily medicine, say, a triterpenoid, that barely mixes with water; it settles right into that pocket. Held there, not by strong links, but by gentle pulls between surfaces. These include fleeting attractions and the way oil, avoiding parts group together. What keeps it all intact? Tiny forces, shifting constantly, like quiet tugs beneath stillness.

Upon inclusion of the drug molecule, the following effects occur:

Water molecules escape once trapped inside the cyclodextrin structure. Trapped droplets break free from their ring, shaped cage. The molecular container lets go of its held moisture. Moisture exits after being locked within the cyclic compound. Held HO slips out when the host structure opens up.

Stability climbs, so the complex slips in more easily. The setup holds firm, helping things fit together. As balance improves, integration follows without effort. When the environment steadies, assembly happens naturally. A solid base allows connection to take place smoothly.

Water dissolves the medicine more easily now. The compound mixes better when wet. Its ability to blend into liquids has gone up. This version spreads faster in fluid. Liquid takes it in quicker than before.

So now, medicines that dont mix well with water can dissolve better, making them last longer inside the system while entering the bloodstream faster. One change fixes multiple issues at once, solubility lifts, absorption follows.

A good instance is how hydroxypropyl, cyclodextrin (HP, CD) often serves as a helper substance that boosts water, based solubility, seen with compounds like oleanolic acid, betulinic acid, madecassic acid.[6,7]

2. Improving the Permeation of Drugs Through Cell Membranes

Cyclodextrins can alter the cell membrane. It might alter the cell membrane a little because the cyclodextrin might interact with the fat molecules already present. In other words, they might loosen the membrane a little or alter its shape temporarily.

In a study involving mistletoe extract, the study showed that the ability of lectins to penetrate cancer cells was improved by the dissolved triterpenes using HP-β-CD. It is likely that the ability of the dissolved compounds to alter the membrane structure because of their fat-soluble nature allows the other compounds to penetrate the membrane[8]

3. Altering cholesterol and lipid rafts

3.Altering cholesterol and lipid rafts Cholesterol gets pulled out by some cyclodextrins, these molecules latch onto it within the cell's outer layer. When cholesterol levels shift there, how cells send and pick up messages changes too. That happens because cholesterol helps form lipid rafts, special spots in the membrane where chatter between cells takes place. Those pockets rely on cholesterol to keep things running. [9]

These ideas still under study for that purpose: Fighting illnesses that kill brain and nerve cells begins here. Stopping conditions that destroy neurons matter more every day. Nerve cell loss from certain diseases can slow when addressed early. Dead nerves due to sickness might be prevented with proper care. Some disorders lead to dying nerve tissue, this targets those Tackle infections from viruses Investigate unusual lipid storage diseases Investigate cancer [10]

4. Controlled and Extended Drug Release

Wrapped around drug molecules, cyclodextrins fit neatly into gels meant for skin use. Such pairings tend to hold ingredients stable while easing delivery through outer layers. Their presence often improves how long a dose lasts once applied. Stability gets a quiet boost without changing the formula much. Sometimes, irritation drops when active parts are shielded just right [11]

❖ Increasing the amount of drugs in the area

Slow delivery happens over time. A gradual flow keeps things moving. This method releases bit by bit. Movement stays consistent without spikes. Release timing stretches out evenly

❖ Accelerating the healing of wounds

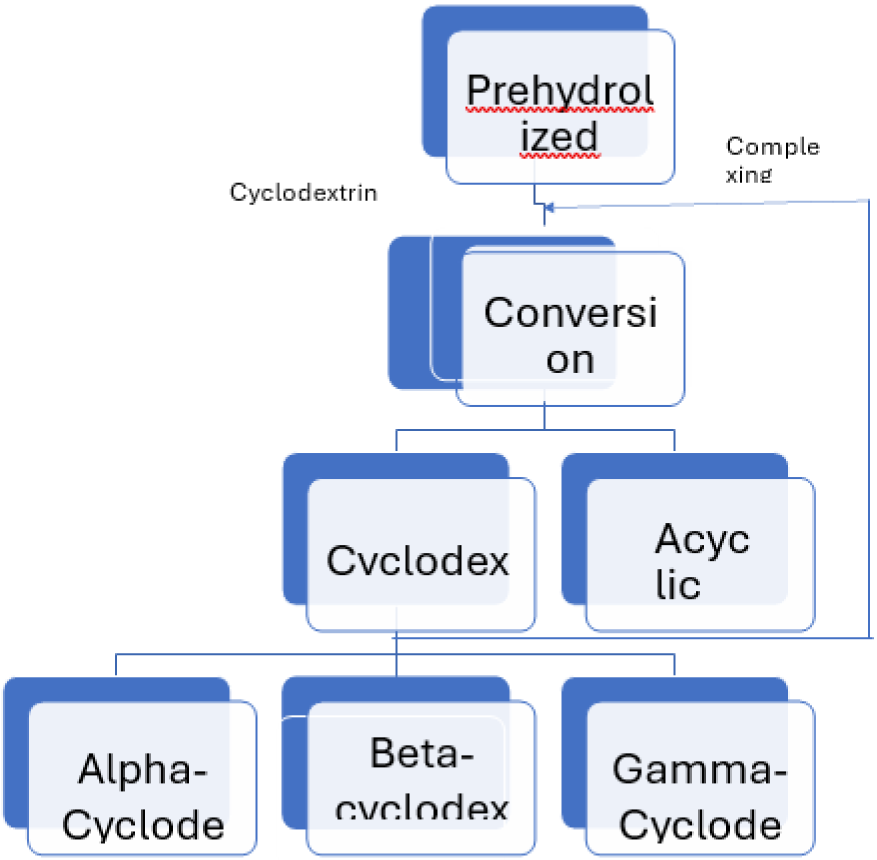
Stability improves when adjustments are made. Handling gets simpler as balance increases. A steady setup often follows small tweaks. Control feels more natural once shifts occur. Smooth operation tends to emerge from careful changes

A single case shows asiaticoside, drawn from Centella asiatica, linking up with HP, CD so it stays in the system longer while slipping into tissues more easily, helping wounds mend faster.[12]

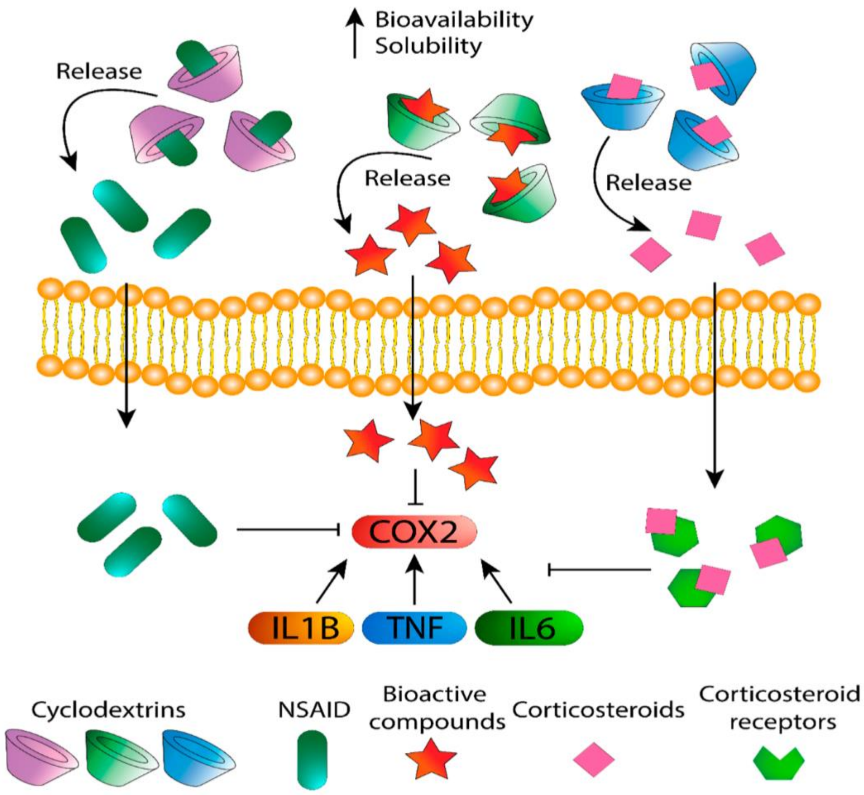
5. Keeping things safe and stable

Buried within cyclodextrins, fragile medicines stay shielded from outside threats. Because of this pocket, like space, breakdown from exposure slows down noticeably.[13]

Flow chart:



3. Altering cholesterol and lipid rafts



ADVANTAGES OF CYCLODEXTRINS

- Solubility and Bioavailability Enhancement: The formation of inclusion complexes is their main feature that enhances the solubility of poorly water, soluble compounds in aqueous medium. This improves the bioavailability and absorption of a number of drug compounds, together with controlling the drug plasma level.[14]
- Stability and Protection: CDs shield vulnerable drug compounds from environmental degradation, including photodegradation, thermal exposure, oxidation, and enzymatic breakdown. This is a way in which products such as pharmaceuticals, food, and cosmetics can have an extended shelf, life. Controlled [15]
- Targeted Delivery: Stimuli, responsive drug release, e.g. the release of a drug upon a pH change within a tumor, can be facilitated by CDs, in addition to other release profiles such as sustained release.
- Patient Compliance and Safety: CDs can mask the unpleasant taste or smell of drugs given orally. CDs can also help reduce the volatility of essential oils. Besides, complexation can lessen the irritating effects of a drug on the gastrointestinal tract or the skin. Active
- Therapeutic Potential: Apart from being drug carriers, CDs have been used for the treatment of diseases. As an example, hydroxypropyl, cyclodextrin (HPCD) is employed for cholesterol removal in Niemann, Pick type C and Alzheimers diseases. Sugammadex, a modified, CD, is used for the reversal of anesthesia and acts by encapsulating the anesthetic agents.
- Advanced Gene and Vaccine Applications: CDs are a practical way to protect the mRNAs, siRNAs, and DNAs that pass through them from being degraded and, at the same time, getting inside cells. Besides, CDs are the subject of extensive studies to find ways to use them as a safe adjuvant that may help to strengthen immunity and at the same time reduce the side effects when compared to traditional aluminum, based adjuvants.Environmental Remediation CDs are excellent sorbents that can be used to capture organic compounds such as pesticides and hydrocarbons, heavy metals, and even VOCs from water and soil.[16]

DISADVANTAGES OF CYCLODEXTRIN

- Organ, Specific Toxicity (Parenteral Route)Native, cyclodextrin has generally been considered safe when taken by mouth, however, it has been found to cause nephrotoxicity (kidney damage) when administered intravenously or intramuscularly on the basis of the accumulation of the compound in the tubules of kidneys.

- Ototoxicity It has been known that large amount of HPCD can cause total or partial sensorineural deafness in a significant amount of the population undergoing this treatment as a result of clinical trials in patients with type C of the group of diseases called Niemann, Pick.[17]
- Risk of Drug Overdose But, in the case of significantly raising the bioavailability of drug, the use of the CD complex may cause unintentional overdoses of the drug, which in turn can lead to toxicity if the drug dosage is not properly regulated.
- Formulation Challenges: CDs are capable of interacting with other ingredients of a product, such as antimicrobial preservatives. These interactions could decrease the availability and efficiency of CDs in multidose formulations. Besides, it can be tough to make complex systems of CDs and polymers on a clinical scale.
- Membrane Disruption: Certain highly substituted or methylated derivatives have a strong tendency to bind to lipid membranes. This may result in cell membrane disruption and cytotoxicity.
- Off, Target Protein Effects: At millimolar concentrations, which are sometimes necessary for treatment, CDs are capable of binding and altering the function of other cellular proteins in an off, target way. For example, ion channels (e.g., KV1.3 and TASK [channels).[18]

ROLE OF BIOMOLECULES

Neuroplasticity means that the brain can change and adapt at any age by making new connections between brain cells. It is most noticeable in early childhood, when brain cells are being pruned and myelinated. Studies have shown that stimulating the environment and learning have a direct effect on the thickness of the cortex and the branching of the dendrites. Functional magnetic resonance imaging has shown that the adult brain can still change. This ability of the brain is what lets it heal from injuries and learn new things. The neuroplasticity model has very important effects on education and rehabilitation medicine[19]

In fact, new drug formulas have been developed with stabilizers or excipients that preserve the structure of biologics to escape these regulations. As a matter of fact, cyclic oligosaccharides, which come from starch, are the strongest stabilizers of peptides and proteins. Called cyclodextrins, the molecules of these cyclic oligosaccharides have a unique structure, as they are hydrophilic on the outside and hydrophobic on the inside. So, they are capable of holding a molecule or a part of a molecule that is hydrophobic by forming inclusion complexes.

Cyclodextrins may behave as a type of artificial molecular chaperone when they bind to biological molecules in this manner. They help in stabilizing the natural conformations of these biological molecules and inhibiting their unfolding. In addition, cyclodextrins can be used to promote protein folding that has been disrupted in order to produce the native and biologically active conformation. This method is able to safeguard and increase the stability and shelf life of peptide and protein preparations. Many cyclodextrin derivatives have been examined as possible stabilizers for therapeutic molecules. Among them, -cyclodextrin and its derivatives such as methyl--cyclodextrin (MCD), hydroxypropyl--cyclodextrin (HPCD) and sulfobutyl ether--cyclodextrin (SBECD) have been extensively studied for their roles as stabilizers of major therapeutic proteins and their potentials in preventing the protein aggregation thereby enhancing the stability of these proteins.[20] For example, cyclodextrin derivatives were applied to stabilize the hormone insulin to prevent it from forming inactive aggregates. Likewise, the interactions with cyclodextrin derivatives even helped in maintaining the biological functions of other major therapeutic proteins like human growth hormone and granulocyte colony-stimulating factors Besides their primary function as excipients in pharmaceutical drugs, cyclodextrins have the potential to affect biomolecules related to diseases. For instance, in neurodegenerative disorders like Alzheimer's and Parkinson's diseases, the misfolding and aggregation of certain biomolecules such as amyloid- peptides or -synuclein lead to the generation of protein aggregates[21]. Literature has proven the ability of cyclodextrins to bind and even dissolve abnormal aggregates of amyloid- peptides through hydrophobic interactions. If anything, this suggests the possibility of using cyclodextrins as an essential ingredient of therapeutic formulations for diseases resulting from the abnormal aggregation of biomolecules. Looking at the bigger picture, peptides and proteins as biomolecules will be an indispensable part of future therapeutic strategies. However, due to the inherent instability of biomolecules, there is a necessity for advanced formulation methods. Here, cyclodextrins come to the rescue by maintaining the stability of biomolecules in the formulation of pharmaceuticals, which is a major step in drug development.[22]

CYCLODEXTRINS AS ACTIVE AGENT IN DISEASE MANAGEMENT

Cyclodextrins (CDs) are ring-shaped sugar molecules that are widely used in drug and medical research. They have the ability to retain hydrophobic molecules within their hollow interior. One of the most important advantages is their ability to bind and regulate cholesterol. The hydrophobic core within them enables them to extract cholesterol from cell membranes and within cells, thus regulating fat balance. This property has recently gained attention for its use in treating diseases in which excess cholesterol accumulates. Among various types, hydroxypropyl--cyclodextrin (HPCD) has been explored the most and holds immense potential for the treatment of various diseases And researchers have used HPCD in various disorders to understand its mechanism within the body. The mechanism of extracting cholesterol is not passive. Cholesterol can be extracted from lipid-rich regions by the molecule itself. However, some studies indicate that the body may not be able to remove the cholesterol as efficiently as expected.[22]

NIEMANN-PICK TYPE C DISEASE

Nobody expects cholesterol to get stuck inside cells. Yet that happens in Niemann-Pick type C, a rare inherited condition where fat moves wrong within cell parts. When NPC1 or NPC2 genes change, they break how cholesterol leaves lysosomes. Trapped lipids pile up, harming nerves over time. Liver trouble follows. Death comes sooner than it should. Doctors still lack a sure fix for this illness. That gap pushes science toward fresh ideas. Tiny rings made of sugar, one type being hydroxypropyl--cyclodextrin, might help people with NPC disease. [23]

ALZHEIMER DISEASE

Alzheimer's disease is a degenerative neurologic disorder characterized by progressive memory failure, cognitive decline, and behavioural issues. An increasing body of literature supports the Alzheimer's disease is a degenerative neurologic disorder characterized by progressive memory failure, cognitive decline, and behavioural issues. An increasing body of literature supports that an imbalance in cholesterol metabolism, and lipid deposits within the brain are a contributing factor to the pathogenesis of Alzheimer's disease. The imbalance in cholesterol can lead to the formation of β-amyloid plaques and the induction of neuroinflammation, which will cause neuronal damage.at an imbalance in cholesterol metabolism, and lipid deposits within the brain are a contributing factor to the pathogenesis of Alzheimer's disease. The imbalance in cholesterol can lead to the formation of β-amyloid plaques and the induction of neuroinflammation, which will cause neuronal damage.[24]

PARKINSON DISEASE

Parkinson’s disease is another neurodegenerative disorder that include the progressive deterioration of dopaminergic neurons in the brain, especially in the substantia nigra. This disorder results in symptoms like tremors, stiffness, bradykinesia, and difficulty with motor coordination. Recent research has indicated that dyslipidemia and cholesterol imbalance could be involved in the degeneration of neurons in Parkinson’s disease.
Cyclodextrins could be useful in the treatment of Parkinson’s disease due to their cholesterol-lowering effects. Hydroxypropyl-β-cyclodextrin can be used to normalize lipid metabolism and induce cellular processes that remove toxic protein clumps. Experimental research has shown that deliver cyclodextrin could increase autophagy, which is a cellular process that remove dysfunctional proteins and organelles. By improving cellular homeostasis and reducing toxic protein accumulation, cyclodextrins could protect dopaminergic neurons and potentially slow disease progression.[25]

ATHEROSCLEROSIS

Atherosclerosis is a cardiovascular disease characterized by the deposition of cholesterol and lipid-laden plaques in the arterial walls. This can cause the blood vessels to become narrower and the blood flow through the vessels to be reduced. Atherosclerosis can result in heart attacks and strokes. The buildup of cholesterol in the macrophages of the arterial walls causes these cells to become foam cells, which is the main reason for atherosclerosis. In fact, Cyclodextrins have been shown to be capable of significantly reducing cholesterol accumulation in arterial walls. Cyclodextrins can form stable complexes with cholesterol molecules and help in extracting cholesterol from macrophages and other cells in the arterial walls. This may result in the breakdown of cholesterol crystals and lessening of atherosclerosis. Cyclodextrins may be considered as a therapeutic option for atherosclerosis and related cardiovascular diseases.

VIRAL INFECTIONS AND COVID-19

Cyclodextrins could potentially be another mechanism for antiviral drugs. For instance, the anti-COVID-19 medication Veklury (remdesivir) is formulated with the cyclodextrin derivative sulfobutylether--cyclodextrin as the solvent. Actually there are quite a few research articles reporting on the potential of the cyclodextrin as a component in antiviral therapy. This cyclodextrin might alter the function of lipid rafts in membranes of cells. Since lipid rafts are essential for viral infections/cell entry tubulin cyclodextrins affecting lipid rafts could prevent the virus from entering the cell and therefore complement the antiviral drugs.[26]

FUTURE PROSPECT

The potential of cyclodextrins (CDs) remains very high because of the fast progress of chemistry, biotechnology, and material science. Perhaps the most significant contribution that can be expected from future cyclodextrin research is the creation of innovative cyclodextrin derivatives. Nowadays, it is quite achievable, even with fairly simple methods, to get cyclodextrins that are much more selective, soluble, and compatible with a living body. This way, new cyclodextrins offer not only efficient ways of forming complexes but also desirable drug release profiles. On the other hand, it should be emphasized that structural and thermodynamic aspects of guest inclusion into CDs can be reliably accounted for using computational chemistry methods, which have come up as powerful tools and exposed the molecular level of the host-guest interaction in a very detailed fashion. Thus, it is expected that in the near future, jobs related to this type of work by the use of AI and machine learning will not only be speeding up but also getting much more precise and reliable.[27]

drug delivery systems. They are particularly promising for the delivery of biologics (e.g. peptides proteins, At the pharmaceutical level, the main functions of cyclodextrins are likely to be further augmented in advanced and nucleic acids) that are highly vulnerable to degradation and have low bioavailability. CDs are able to protect these drugs against breakdown, and they also allow for targeted and controlled drug release. At the same time, the combination of CDs with liposomes and polymeric nanoparticles as nanocarriers not only leads to the stimulation of drug activity but also to the mitigation of side effects risk. On the other hand, CD-based formulations designed according to the genetic profile and disease status of individual patients will give rise to the new field of personalized medicine. In addition, responsiveness of CDs to stimuli, meaning the release of drug molecules following the detection of certain biological cues will thereby, augment the effectiveness of therapies.[28] Cyclodextrins are also observed in other than strictly pharmaceutical fields where food cosmetics textiles, and industrial applications are being recognized more and more. Through their property to sequester contaminants, including drugs residues and microplastics, CDs can provide environmentally friendly ways for pollution control. In a circular economy context, CD-based materials might be able to facilitate the recovery and reuse of valuable substances from waste streams. In food, cosmetics, and textile manufacturing, CDs are anticipated to serve increasingly as stabilizers, preservatives, and functional additives with the development of smart CD-based materials that are capable of responding to environmental changes could be the first step towards a change of entire packaging industry's technologies by, on one hand, extending shelf life of products and, on another hand, significantly reducing waste. With the increase of their applications, safety and toxicological evaluation aspects will covet a higher priority in becoming.[29] The modern in vitro and in silico methods, including predictive toxicology and high-throughput screening, are going to be a must to evaluate the safety of the newly developed CD derivatives. Furthermore, the long-term work for chronic exposure and environmental effects will help to determine risk, usage, and sustainability. The joint effort of scientific communities, businesses, and lawmakers will indeed facilitate the development of thorough safety standards. Lastly, cyclodextrins will most likely be present in new technologies. In biotechnology, they can not only stabilize enzymes but also improve their catalytic performance in biocatalytic processes. Regarding clean energy, CDs could be instrumental in the realization of better energy storage mechanisms such as batteries and supercapacitors through the stabilization of active materials. Additionally, their

Intelligence is going to open up new ways to innovate in predicting the behaviour of complexation. To conclude, cyclodextrins indeed represent a rapidly advancing area with extensive potential for future developments, offering ground-breaking solutions in various scientific and industrial fields among other things.[30]

CONCLUSION

Cyclodextrins have become a major player in drug delivery systems and therapeutic research due to their special structure that grants them the ability to improve the solubility, stability, and bioavailability of drugs with very low water solubility. As a result, cyclodextrins became a key factor in helping the major shortcomings of natural compounds like triterpenes be overcome and at the same time, make their use as therapeutics more effective. In addition to their role in natural compounds, cyclodextrins have revealed that they can be used as drugs themselves by exploiting the fact that they help the removal of the body's cholesterol, thus have been involved in the treatment of a wide range of disorders including neurodegenerative, cardiovascular, and viral. Besides that, they improve the stability of proteins and peptides which is of utmost importance during the development of biologics.

However, there are still some risks associated with them, including toxicity, formulation and specificity problems, that need to be carefully handled to ensure their safe use. In general, cyclodextrins can be viewed as a very promising means of combining drug delivery and action. Considering the continuous progress in their chemical modification, these compounds will play a significant role in the invention of more effective, targeted and safe drugs to the wide spectrum of human diseases, in the near future.

REFERENCE

1. Poulson BG, Alsulami QA, Sharfalddin A, El Agammy EF, Mouffouk F, Emwas AH, Jaremko L, Jaremko M. Cyclodextrins: Structural, chemical, and physical properties, and applications. Polysaccharides. 2021 Dec 28;3(1):1-31.
2. Peron G, Marzaro G, Dall'Acqua S. Known triterpenes and their derivatives as scaffolds for the development of new therapeutic agents for cancer. Current medicinal chemistry. 2018 Mar 1;25(10):1259-69.
3. Thomford NE, Senthebane DA, Rowe A, Munro D, Seele P, Maroyi A, Dzobo K. Natural products for drug discovery in the 21st century: innovations for novel drug discovery. International journal of molecular sciences. 2018 May 25;19(6):1578.

4. Di Cagno, M. P. (2017). The Potential of Cyclodextrins as Novel Active Pharmaceutical Ingredients: A Short Overview. *Molecules*, *22*(1), 1. https://doi.org/10.3390/molecules22010001
5. Crini G. (2014). Review: a history of cyclodextrins. *Chemical reviews*, *114*(21), 10940–10975. https://doi.org/10.1021/cr500081p
6. Esteso, M. A., & Romero, C. M. (2024). Cyclodextrins: Properties and Applications. *International Journal of Molecular Sciences*, *25*(8), 4547. https://doi.org/10.3390/ijms25084547
7. Morin-Crini N, Fourmentin S, Fenyvesi É, Lichtfouse E, Torri G, Fourmentin M, Crini G. 130 years of cyclodextrin discovery for health, food, agriculture, and the industry: A review. Environmental Chemistry Letters. 2021 Jun;19(3):2581-617.
8. Ali R. Cyclodextrins-Core Concepts and New Frontiers. 2023 Feb 1.
9. Soe HM, Kerdpol K, Rungrotmongkol T, Pruksakorn P, Autthateinchai R, Wet-Osot S, Loftsson T, Jansook P. Voriconazole eye drops: enhanced solubility and stability through ternary voriconazole/sulfobutyl ether β-cyclodextrin/polyvinyl alcohol complexes. International Journal of Molecular Sciences. 2023 Jan 25;24(3):2343.
10. Galindres DM, Espitia-Galindo N, Valente AJ, Sofio SP, Rodrigo MM, Cabral AM, Esteso MA, Zapata-Rivera J, Vargas EF, Ribeiro AC. Interactions of Sodium Salicylate with β-Cyclodextrin and an Anionic Resorcin [4] arene: Mutual Diffusion Coefficients and Computational Study. International Journal of Molecular Sciences. 2023 Feb 15;24(4):3921.
11. Sierpe R, Donoso-González O, Lang E, Noyong M, Simon U, Kogan MJ, Yutronic N. Solid-state formation of a potential melphalan delivery nanosystem based on β-cyclodextrin and silver nanoparticles. International Journal of Molecular Sciences. 2023 Feb 16;24(4):3990.
12. Sangkhawasi M, Kerdpol K, Ismail A, Nutho B, Hanpiboon C, Wolschann P, Krusong K, Rungrotmongkol T, Hannongbua S. In vitro and in silico study on the molecular encapsulation of α-tocopherol in a large-ring cyclodextrin. International Journal of Molecular Sciences. 2023 Feb 23;24(5):4425.
13. Gao S, Yang G, Zhang X, Shi R, Chen R, Zhang X, Peng Y, Yang H, Lu Y, Song C. β-Cyclodextrin polymer-based fluorescence enhancement strategy via host–guest interaction for sensitive assay of SARS-CoV-2. International Journal of Molecular Sciences. 2023 Apr 12;24(8):7174.

14. Miranda, G. M., Santos, V. O. R. E., Bessa, J. R., Teles, Y. C. F., Yahouédéhou, S. C. M. A., Goncalves, M. S., & Ribeiro-Filho, J. (2021). Inclusion Complexes of Non-Steroidal Anti-Inflammatory Drugs with Cyclodextrins: A Systematic Review. *Biomolecules*, *11*(3), 361. https://doi.org/10.3390/biom11030361
15. Davis, M. E., Zuckerman, J. E., Choi, C. H., Seligson, D., Tolcher, A., Alabi, C. A., Yen, Y., Heidel, J. D., & Ribas, A. (2010). Evidence of RNAi in humans from systemically administered siRNA via targeted nanoparticles. *Nature*, *464*(7291), 1067–1070. https://doi.org/10.1038/nature08956
16. Haley, R.M., Gottardi, R., Langer, R. *et al.* Cyclodextrins in drug delivery: applications in gene and combination therapy. *Drug Deliv. and Transl. Res.* **10**, 661–677 (2020). https://doi.org/10.1007/s13346-020-00724-5
17. Dun-Sheng Yang, Philip Stavrides, Asok Kumar, Ying Jiang, Panaiyur S. Mohan, Masuo Ohno, Kostantin Dobrenis, Cristin D. Davidson, Mitsuo Saito, Monika Pawlik, Chunfeng Huo, Steven U. Walkley, Ralph A. Nixon, Cyclodextrin has conflicting actions on autop
18. Zuobing Xiao [a b], Ziyao Xu [a], Liyuan Zhou [a], Yanxiang Kang [a], Yunwei Niu [a], Di Zhao [a] hagy flux *in vivo* in brains of normal and Alzheimer model mice, *Human Molecular Genetics*, Volume 26, Issue 5, 1 March 2017, Pages 843–859, https://doi.org/10.1093/hmg/ddx001
19. Yan H, Kamiya T, Suabjakyong P and Tsuji NM (2015) Targeting C-Type Lectin Receptors for Cancer Immunity. Front. Immunol. 6:408. doi: 10.3389/fimmu.2015.00408
20. Almeida, B., Domingues, C., Mascarenhas-Melo, F., Silva, I., Jarak, I., Veiga, F., & Figueiras, A. (2023). The Role of Cyclodextrins in COVID-19 Therapy—A Literature Review. *International Journal of Molecular Sciences*, *24*(3), 2974. https://doi.org/10.3390/ijms24032974
21. Bi-Lian Li, Jin Zhang, Wen Jin, Xiang-Yu Chen, Jian-Mei Yang, Shao-Ming Chi, Qiong Ruan, Yan Zhao
22. Cutrignelli, A., Sanarica, F., Lopalco, A., Lopedota, A., Laquintana, V., Franco, M., Boccanegra, B., Mantuano, P., De Luca, A., & Denora, N. (2019). Dasatinib/HP-β-CD Inclusion Complex Based Aqueous Formulation as a Promising Tool for the Treatment of Paediatric Neuromuscular Disorders. *International Journal of Molecular Sciences*, *20*(3), 591. https://doi.org/10.3390/ijms20030591
23. Braga, S. S. (2023). Molecular Mind Games: The Medicinal Action of Cyclodextrins in NeurodegenerativeDiseases. *Biomolecules*, *13*(4), 666. https://doi.org/10.3390/biom13040666

24. Yao, J. and Beal, F. (2012), P4-227: Neuroprotective effects of cyclodextrin in Alzheimer's disease. Alzheimer's & Dementia, 8: P714-P715. https://doi.org/10.1016/j.j
25. Emin, D., Zhang, Y.P., Lobanova, E. *et al.* Small soluble α-synuclein aggregates are the toxic species in Parkinson's disease. *Nat Commun* **13**, 5512 (2022)
26. Dowdy, S. Overcoming cellular barriers for RNA therapeutics. *Nat Biotechnol* **35**, 222–229 (2017). https://doi.org/10.1038/nbt.3802
27. Mazurek, A. H., & Szeleszczuk, Ł. (2022). Current Status of Quantum Chemical Studies of Cyclodextrin Host–Guest Complexes. *Molecules*, *27*(12), 3874. https://doi.org/10.3390/molecules27123874
28. Jitapunkul, K., Toochinda, P., & Lawtrakul, L. (2021). Molecular Dynamic Simulation Analysis on the Inclusion Complexation of Plumbagin with β-Cyclodextrin Derivatives in Aqueous Solution. *Molecules*, *26*(22), 6784. https://doi.org/10.3390/molecules26226784
29. Pang, A. S.-R., Dinesh, T., Pang, N. Y.-L., Dinesh, V., Pang, K. Y.-L., Yong, C. L., Lee, S. J. J., Yip, G. W., Bay, B. H., & Srinivasan, D. K. (2024). Nanoparticles as Drug Delivery Systems for the Targeted Treatment of Atherosclerosis. *Molecules*, *29*(12), 2873. https://doi.org/10.3390/molecules29122873
30. Li, X., Shen, X., Jiang, W., Xi, Y., & Li, S. (2024). Comprehensive review of emerging contaminants: Detection technologies, environmental impact, and management strategies. *Ecotoxicology and environmental safety*, *278*, 116420. https://doi.org/10.1016/j.ecoenv.2024.116420