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Niosome-Based Approaches in Ocular Drug Delivery: Advances, Challenges, And Future Perspectives

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Abstract

The delivery of drugs into the eye is an important issue because there are physiological barriers to the delivery of drugs that include tear turnover, corneal impermeability, and nasolacrimal drainage. Traditional formulae do not readily attain therapeutic concentrations at the desired site and the need to develop new delivery systems has arisen. Non-ionic surfactant-based vesicular carriers (niosomes) have become a promising alternative to liposomes and conventional dosage forms because of their biocompatibility, stability and encapsulation of both hydrophilic and lipophilic drugs. The review indicates the concepts of the niosome technology, current development trends in the field of ocular applications, and the benefits of the niosome technology over the traditional systems. The most important studies that investigate the therapeutic outcomes of treating such conditions as glaucoma, conjunctivitis, retinal disorders are presented, as well as the problem of stability, scalability, and ocular irritation. The paper ends by identifying gaps in the research and proposing areas of future growth, which makes the niosomes an effective approach to transform ocular therapeutics.

Key Words:

Niosomes, Ocular drug delivery, Nanocarriers, Glaucoma, Retinal disorders, Controlled release, Bioavailability, Non-ionic surfactants.

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1. INTRODUCTION

The eye is an extremely vulnerable and complicated organ that not only serves the purpose of vision but also makes people be able to communicate not only with the surrounding world but also to lead a high quality of life[1]. Disability of the ocular functionality may have a profound toll on

day-to-day life, self-sufficiency, and general well-being. Although ophthalmology has improved, there is still a great challenge in the effective treatment of eye malfunctions. This challenge is associated with the special structural and physiological impermeability of the eye, tear turnover, blinking, corneal impermeability, and nasolacrimal drainage which cumulatively restrict drug uptake and constrain the therapeutic potential of traditional preparations, like eye drops and ointments[2]. Moreover, the blood-ocular barriers used to block the injection of drugs are usually protective making a drug to reach the posterior part of the eye difficult to treat diseases like age-related macular degeneration, diabetic retinopathy and retinal degeneration.

These shortcomings have led to the ongoing production of novel ophthalmic drug delivery systems that are meant to improve drug bioavailability, prolong the precorneal retention time and reduce systemic side effects[3]. It is in this regard that nanotechnology methodologies such as liposomes, nanoparticles, and micelles, and more recently the niosomes have become of great interest. These systems do not only provide the ability to do controlled and sustained release, but also enhance the ability to do drugs in a targeted way. Niosomes, or vesicular carriers, made of non-ionic surfactants and cholesterol, are amongst them and are proving to be versatile, inexpensive and biocompatible in nature and have the potential to address much of the drawbacks that come with conventional therapies[4].

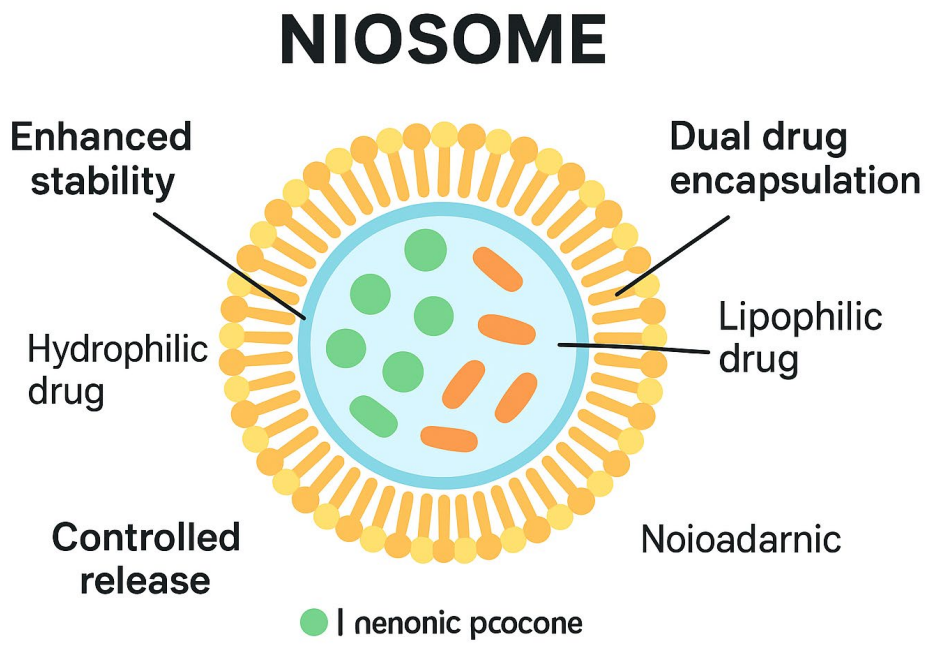

Figure 1: Schematic Representation of Niosome Structure and Drug Encapsulation Mechanism

1.1. Background of the study

Eye ailments like glaucoma, keratitis, and age related macular degeneration (AMD) pose a serious health issue in the world and the diseases can cause a lot of visual impairment and blindness in the event that they are not treated at the initial stages. The weight of such conditions is further increased by unique anatomical and physiological obstacles of the eye, which are created to preserve such an unprotected organ and at the same time limit therapeutic intervention[5]. The

defence functions of nature such as tear turnover, blinking, corneal impermeability, high precorneal clearance and nasolacrimal drainage are significant barriers to effective drug delivery by reducing the absorption and extending the residence time of the dose formulation. Therefore, the traditional dosage ophthalmics in the form of eye drops, ointments, and suspensions tend to fail to reach the target site with therapeutic drug levels[6]. These disadvantages not only lead to sub-therapeutic levels and ineffective clinical outcome but also to the necessity of frequent dosage, which also diminishes patient compliance and overall therapeutic outcome.

In a bid to address these difficulties, there is an emerging tendency among researchers towards development of enhanced drug delivery systems, especially nanotechnology-based systems, as the hopeful approaches in ocular therapy enhancement. Nanoparticles, nanocarriers, such as liposomes, nanoparticles, micelles and dendrimers, have been explored in terms of their benefits in increasing drug penetration, extending retention, and gaining control of release profiles. Among these, niosomes, i.e. vesicular carriers composing of non-ionic surfactants and cholesterol have been of extraordinary interest. Their structural diversity, biocompatibility and their capacity to entrap hydrophilic/lipophilic drugs gives them unique benefits. In comparison with liposomes, niosomes exhibit high level of chemical stability, cost effectiveness, scalability, and sustained drug release properties. Such characteristics render them very appealing alternative sources of ocular drug delivery, the use of which could transform the way disorders of the anterior and posterior segment are handled[7].

1.2. Objectives of the Review

The present review is structured with the following objectives:

- To provide a comprehensive overview of niosome-based drug delivery systems in ocular therapeutics.
- To summarize key experimental and clinical findings reported in recent literature.
- To critically evaluate the advantages, limitations, and challenges associated with niosomal formulations.
- To highlight future perspectives and research directions for their successful clinical translation.

1.3. Importance of the Topic

The investigation of sophisticated drug delivery systems that are applied to the eye is important so that better therapeutic effects can be obtained and patients can adhere to treatment processes in the long run[8]. The shortcomings of traditional ophthalmic formulations have also been known since ancient times, namely, the inability to sustain therapeutic drug levels at the site of activity because of rapid clearance and low ocular penetration across the body barriers. Vesicular carriers like niosomes are therefore a new and versatile platform that can be used to revolutionize ophthalmic drug delivery. Due to their distinctive structure, niosomes can entrap both lipophilic and hydrophilic drugs, which improves the solubility, stability, and bioavailability of drugs. Their capacity to extend the release of drugs, enhance its corneal penetration and limit systemic absorption makes them especially beneficial with respect to chronic ocular ailments which

necessitate constant drug dispersion including glaucoma, keratitis and retinal degenerative conditions[9].

In addition to their therapeutic effectiveness, niosomes can be seen as a novel step towards the integration of the conventional ophthalmic formulations with the yet developing area of nanomedicine. They merge familiarity and relative security of the established drug delivery methods with the novelty and accuracy of nanotechnology. In addition, their cost-effectiveness, structural stability, and scalability provide them with an advantage over other nanocarriers such as liposomes and hence can be used in research and possibly a translation to practice. Knowing their potential, as well as managing the challenge related to them, is hence crucial, not only in developing ophthalmic therapeutic potential, but also in fulfilling urgent clinical requirements in vision threats prevention and management. Future research into niosome-based delivery systems might eventually lead to more effective approaches to delivery systems that are patient friendly and cost effective, which will benefit the lives of millions suffering ocular disorders in the world[10].

2. FUNDAMENTALS OF NIOSOMES IN DRUG DELIVERY

Niosomes are microscopic vesicles that are self assembled which are based mostly on non-ionic surfactant with cholesterol or other stabilizing reagents. They have a similar structure to liposomes except that they contain synthetic surfactant instead of phospholipids, which makes them quite cost-effective and with higher chemical stability. This distinctive bilayer property of the niosomes enables them to be able to envelop a large variety of therapeutic agents, hydrophilic drugs are placed in the aqueous core, and lipophilic drugs are intercalated in the lipid bi-layer membrane. Their combined encapsulation properties ensure such versatility that make them a unique ideal carrier of varied pharmaceutical uses, especially in the area of ocular therapy where compliance with drugs and drug penetration through cells is a big problem. Addition of cholesterol or other membrane stabilizers further enhances rigidity, decreases membrane permeability as well as minimizing the premature leakages of the encapsulated drug which in turn provides controlled and sustained release of the drug.

According to their structural arrangement, niosomes can be classified into three broadly. Multilamellar vesicles (MLVs) are made of several concentric bilayers, which appear like an onion and they have great drug loading capacity but their size is relatively large. Unilamellar vesicles (ULVs) are single-bilayer vesicles that, in turn, are more appropriate in cases where a consistent drug release profile is required. Unilamellar vesicles (SUVs) with their smaller size and higher surface area-volume ratio are shown to penetrate tissues better and to be especially beneficial in getting across ocular barriers. The type of vesicle is usually determined by the target that needs a therapeutic intervention and physicochemical characteristics of the drug to be carried.

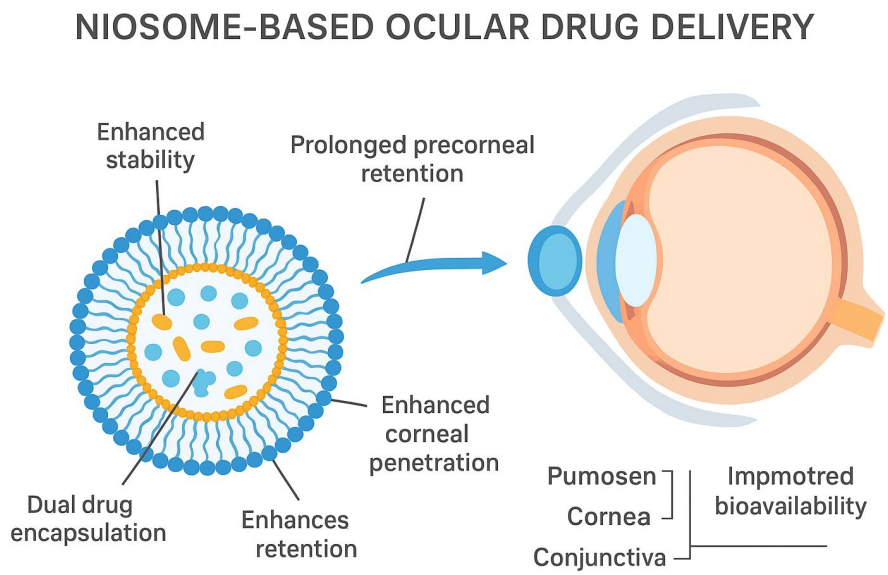

Figure 2: Niosome-Based Ocular Drug Delivery: Mechanism of Action and Therapeutic Advantages

Niosomes have been shown to be effective in the therapy of the eye due to its capacity to surpass the natural defense mechanisms of the eye. They increase the corneal penetration by reacting with the epithelial layer, lengthens the precorneal retention by bioadhesive interactions with the mucin layer and allows the release of drugs to occur at the target site in a sustained and controlled manner. All these properties lead to the increased bioavailability of the drugs, decelerated dose regimen, and increased patient adherence. Moreover, the vesicular structure can be customized by altering surfactant composition, vesicle size, or surface functionalization, and therefore, pharmacokinetic and pharmacodynamic results can be strictly controlled. Therefore, niosomes are becoming a promising platform in contemporary ophthalmic nanomedicine, which can solve the problem that has been previously encountered by drug delivery to the eye**.**

3. METHODOLOGIES IN NIOSOME PREPARATION

Preparation technique is critical in defining the physicochemical properties of niosomes like particle size, lamellarity, surface charge, entrapment efficiency, and, lastly, their therapeutic behavior. The preparation method would thus have to be optimized to get reproducible formulations that can be used in clinical practice. Multiple strategies have been devised with their own set of strengths, weaknesses and use.

- **Thin-Film Hydration Method**

The thin-film hydration method, often known as the hand-shaking method, is the most widely used technique for preparing complete niosomes. This procedure involves dissolving cholesterol and surfactants in an organic solvent, such as methanol or chloroform. Following this stage, a rotary evaporator is used to evaporate the solvent under lower pressure, leaving a thin lipid film on the flask's inner surface. This film is then hydrated using a stirred aqueous drug solution. MLVs, or multilamellar vesicles, are created. This method can readily result in a heterogeneous population

of vesicles with varying sizes, despite the fact that it is simple, affordable, and requires little specialist equipment. Although they decrease encapsulation efficiency, other techniques like sonication or extrusion can be utilized to reduce vesicle size and improve uniformity.

- **Reverse Phase Evaporation Method**

This approach is especially appropriate to the entrapment of hydrophilic drugs and is more entrapment efficient than the method of thin-film hydration. It commences with the formation of the water-in-oil emulsion in which the aqueous layer that houses the drug is emulsified with an organic solvent that has surfactants and cholesterol. When the solvent is gradually removed under reduced pressure vesicles spontaneously form and trap much of the aqueous drug. The reverse phase evaporation technique yields relatively large unilamellar vesicles having high drug loading capacity as it is beneficial when it comes to drugs that have low bioavailability. The application of organic solvents could potentially be toxic, however, solvents have to be removed carefully to guarantee safety of the formulation.

- **Microfluidization and Proniosome-Based Approaches**

Recent developments in the niosome technology have been concerned with enhancing reproducibility, scalability and long-term stability.

  - Microfluidization employs high-pressure homogenization to compel fluid streams through small channels, which produce homogeneous shear forces producing highly homogeneous vesicle populations with small size distributions. The method is very scalable, repeatable and can be applied in industries.
  - Proniosomes are a free-flowing, dry precursor system that is made of surfactants and stabilizers that are coated on a water-soluble carrier like maltodextrin. When the proniosomes are hydrated in-situ, they spontaneously re-form into niosomes and thus effectively address the problem of low stability during storage. The use of proniosomes has a special potential to improve the shelf-life, reduce the aggregation and allow patient-friendly dosage forms.

- **Critical Evaluation**

There are still difficulties in standardizing and scaffolding niosome production to industrial and clinical purposes. Hydration-based techniques like thin-film hydration are easy and inexpensive to use in laboratory scale research but have no reproducibility and control over the properties of the vesicles in large scale production. Reverse phase evaporation is highly encapsulated with high efficiency but uses organic solvents which makes them difficult to be approved by the regulatory authorities. Microfluidization and proniosomes would solve the stability and reproducibility problems, but they need to be validated in terms of cost-effectiveness and scalability to mass production. Consequently, the future studies ought to consider improving process parameters, combining green and solvent free and developing regulatory acceptable manufacturing guidelines that would facilitate the commercialization of niosome based ocular preparations**.**

Table 1: Summary of literature on Niosome-Based Approaches in Ocular Drug Delivery: Advances, Challenges, and Future Perspectives

Author Name	Topic Covered	Research Study Title

Maharana, P. K., Kumar, A., Pandey, A., Sakarkar, S. N., Bisen, P., Pathak, V., ... & Rai, G. K. (2025) [11]	Niosomal drug delivery systems	Developing niosomal drug delivery: production, description, and medicinal uses—a thorough
Mishra, A., Shaima, K. A., & Sindhu, R. K. (2024) [12]	Ocular drug delivery	Novel drug delivery system for ocular target. Nanotechnology and Drug Delivery
Hnin, H. M. (2019) [13]	Ophthalmic delivery using niosome-cyclodextrin complexes	Creation of cyclodextrin/ace inhibitor niosome complexes as an ocular delivery system to reduce intraocular pressure
Nguyen, M. H., Le, T. H. N., Nguyen, T. P. T., Le, T. N. T., Nguyen, T. Y. N., Nguyen, K. A., ... & Le, M. T. (2024) [14]	Targeted drug delivery using niosomes	Recent developments and uses of niosomes in targeted medication delivery. Science and Technology Development Journal at VNUHCM
Hnin, H. M., Stefánsson, E., Loftsson, T., Asasutjarit, R., Charnvanich, D., & Jansook, P. (2022) [15]	Topical niosomal formulations for ocular use	Topical niosomal encapsulating fosinopril/γ-cyclodextrin complex for ocular delivery: physicochemical and stability assessment. Pharmaceutical
Dave, V. S. (2016) [16]	Formulation strategies for ocular drug delivery	formulation strategies for the administration of drugs into the eyes. Nano-biomaterials for the transport of drugs into the eyes

4. THERAPEUTIC APPLICATIONS IN OCULAR DRUG DELIVERY

Over recent years, the use of niosomes in the eye therapeutic approach has received growing interest because of the capacity to overcome the structural and physiological obstacles of the eye. Increasing drug solubility, improving drug corneal penetration, extending precorneal retention, and controlled release, niosomes increase bioavailability of drugs relative to traditional formulations[17]. The characteristics are particularly important in the treatment of chronic eye conditions, where compliance and treatment effectiveness over time are of high importance. Also, niosomes have proven to be versatile across the encapsulation of small-molecule drugs as well as macromolecules, as this has expanded their therapeutic capabilities. The subsequent segments underscore significant regions that niosomal preparations have demonstrated utility in eye treatment.

4.1. Glaucoma Management

One of the major causes of irreversible blindness in the globe is glaucoma, which is majorly caused by increased intraocular pressure (IOP) caused by compromised aqueous humor drain. Traditional topical interventions like timol maleate and pilocarpine lower the IOP but have a quick precorneal clearance and intraoperative effects, which require many daily doses. This does not only lower therapeutic effectiveness but also impacts on patient compliance during long term management[18].

The use of the niosomal formulations of antiglaucoma agents has shown incredible improvements compared to eye drops. As an example, niosomes containing timolol maleate have exhibited an improved penetration of the cornea, prolonged effects of lowering IOP, and the decreased frequency of dosage[19]. Equally, pilocarpine-impregnated niosomes had a better therapeutic outcome, as they exhibited a good IOP management with reduced administration. Such outcomes are of great importance in chronic illness such as glaucoma whereby medication compliance matters a lot to ensure one does not develop to the level of optic nerve damage and blindness.

4.2. Anti-Inflammatory and Anti-Infective Therapy

Topical anti-inflammatory and antimicrobial drugs are often needed in a high frequency to treat ocular inflammatory and infectious diseases including conjunctivitis, keratitis, and postoperative inflammation[20]. Traditional dosing of diclofenac (nonsteroidal anti-inflammatory drug) and ciprofloxacin (fluoroquinolone antibiotic) have low residence time and low corneal permeation resulting in ineffective therapeutic efficacy and high risk of systemic toxicity through excessive dosing.

These drugs have been exhibited to have improved pharmacology when formulated as niosomes. Niosomes carrying diclofenac are better retained in the surface of the eye and have a more prolonged action of anti-inflammation, thus diminishing the number of times to administer it. Likewise, it has been demonstrated that ciprofloxacin-loaded niosomes have a better antimicrobial effect, increased corneal permeation and a more desirable therapeutic index relative to free drug solutions. The fact that the residence time is long and that the systemic absorption is limited is another benefit to the patient and the safety of patients, and thus, niosome systems are good candidates when it comes to ocular infections and inflammations[21].

4.3. Retinal Drug Delivery

Delivery of drugs to the posterior parts of the eye, and retina, especially in ophthalmology is one of the most challenging to overcome even with the presence of barriers in the form of the vitreous humor, blood-retinal barrier, and poor diffusion of drugs. Topical preparations are mostly inefficient in treating retinal diseases and in most cases, invasive treatments such as intravitreal injections are administered.

Niosomal preparations are undergoing research as non-invasive methods of delivering therapeutic agents to the retina[22]. It has been shown that antioxidants and anti-VEGFs, when loaded into niosomes, are able to enter deeper ocular tissue and have therapeutic effects in age-related macular degeneration (AMD) and diabetic retinopathy. The early in vivo studies indicate that not only do niosomes increase the number of drug transfers to posterior ocular parts but also alleviates the necessity of repetitive invasive surgeries therefore limiting the risks of intravitreal injections.

These findings have shown promise of niosomes revolutionizing retinal therapy although further clinical validation would be required[23].

4.4. Gene and Protein Delivery

In addition to traditional small-molecule drugs, another promising field of study is the use of niosomes to deliver macromolecules like peptides, proteins and nucleic acids. Protein-based pharmaceuticals and ocular gene therapy have a great potential in curing inherited retinal infections, corneal dystrophies and chronic degenerative infections. Macromolecules are however susceptible to enzymatic degradation and low membrane permeability thus their usefulness is limited[24].

Niosomes offer a protective layer of bilayer that protects delicate biomolecules against enzyme degradation and transportation across barriers to the eye. Successful encapsulation and delivery of peptides and nucleic acids has been reported with niosomes and stability and bioactivity has been encouraging. In spite of these achievements, a number of problems still exist, such as preserving the vesicles integrity throughout the storage, reducing the immunogenicity, and strict regulation of release kinetics. It could be possible to counter these drawbacks by the development of hybrid niosomal systems, surface functionalities, and stimuli-responsive systems and thereby translate them to the clinic in ocular therapies involving gene and protein delivery[25].

5. COMPARATIVE ADVANTAGES OVER CONVENTIONAL SYSTEMS

With several benefits over conventional ophthalmic preparations (such as eye drops and solutions) and other nanocarrier systems, niosomes have emerged as a particularly effective and practical platform for ocular medication delivery. Their unique bilayer structure, ability to encapsulate hydrophilic and lipophilic medicines, and versatility in working with a wide range of therapeutic agents make them particularly appealing for long-term ocular applications[26].

- **Enhanced Bioavailability:**

The alternate important drawback with the traditional eye drops is that there is a rapid elimination of the drugs in the precorneal area with tear it turnover and blinking leading to poor ocular bioavailability (typically less than 5 percent). The amphiphilic bilayer structure of niosomes enhances the corneal permeability and provides the extended retention in the precorneal zone[27]. This greatly enhances the extent of drug uptake and enables the attainment of greater concentrations to the desired ocular tissues hence enhancing the therapeutic outcome.

- **Sustained Drug Release:**

Niosomes are vesicular and, hence, can serve as controlled and sustained drug release reservoirs. Niosomes can achieve a constant therapeutic level in the eye at a longer time compared to the fluctuating levels of the drug. This saves one the hassle of taking doses frequently which is specifically useful in chronic ocular illnesses like glaucoma, dry eye syndrome, and the retinal disorders which involves prolonged treatment[28].

- **Biocompatibility and Safety:**

Niosomes are formulated by using non-ionic surfactants and cholesterol as the key components and have high biocompatibility and a good safety record. Niosomes are also safe in fragile ocular tissues, whereas some synthetic nanoparticles can result in ocular toxicity, irritation or immunogenicity[29]. The fact that they can wrap drugs in a protective layer further lessens the chances of drug induced toxicity as they would reduce their exposure to the sensitive structures of the eyes[30].

- **Cost-Effectiveness:**

Niosomes are cheap compared to liposomes that need phospholipids that are costly to acquire, and elaborate processes to manufacture. They are commercially viable due to their stability during storage and capacity to be produced in large scale especially in the case of ophthalmic formulations where cost is a key factor to guarantee availability to patients.

All these factors make niosomes one of the most promising methods of delivering drugs to the eyes. Their efficacy, safety and affordability cover significant limitations of the existing treatments and would be a perfect option in the management of both acute and chronic vision threatening conditions.

6. LIMITATIONS AND CHALLENGES

Although niosomes have enormous potential in development of ophthalmic therapeutic delivery, there are various weaknesses that limit its extensive use in clinical practice. As these difficulties demonstrate, continuous research and optimization of the formulation is necessary:

- Niosomes are characterized by low stability, which has a low shelf life because of vesicle aggregation, fusion and loss of drugs with time.
- Environmental conditions like temperature, pH and exposure to light may increase degradation and affect efficacy.
- There is a paucity of clinical translation, most of the studies are done in in vitro or preclinical models and few studies proceed to trials.
- Its chronic usage safety and effectiveness have not been well established yet, posing challenges to the regulatory approval.
- This is because non-ionic surfactants, although relatively safe in most cases, can lead to eye irritation or discomfort in a few patients.
- Some drugs, e.g. hydrophobic, or large biomolecules, might not be entraped with high entrapment efficiency in niosomal vesicles.
- One of the key technical challenges is to achieve accurate control of the release of drugs and be able to target the posterior part of the eye.

7. DISCUSSION

The use of niosomes in delivering drugs to the eye, has become a prospective approach in overcoming the natural barriers that the traditional ophthalmic preparations have. The analysed articles all indicate that niosomal preparations increase drug retention at precorneal zone, increase corneal penetration and deliver a controlled release profile. All these properties lead to improved bioavailability and therapeutic efficacy which in most cases is missing in conventional systems

like eye drops, ointments and suspensions. Niosomes are also suitable to research and potential clinical use because of a balance that exists between storage, cost and safety compared to liposomes and polymeric nanoparticles. Nevertheless, one can notice that the advantages are strongly contingent on the formulation parameters, including the type of surfactant, cholesterol level, and the method of preparation, which determine the size of the vesicles, the level of entrapment, and the kinetics of drug release.

7.1.Implications and Significance

These results have specific implications to chronic ophthalmology disorders like glaucoma, whereby a long term intraocular pressure management and patient compliance is critical to avoiding vision deficits. Antiglaucoma drugs in niosomal formulations have been found to increase the therapeutic duration and decrease the dose schedule, which could enhance compliance. On the same note, the ability of the niosomes to deliver drugs across barriers in the eye creates new therapeutic opportunities in the treatment of the posterior segment diseases like age-related macular degeneration and diabetic retinopathy, which is known to be notoriously hard to cure using conventional dosage forms. Also, their biocompatibility and encapsulation capacity of both hydrophilic and lipophilic agents expands the scope of drugs capable of being delivered in an effective manner, including small molecules to more complex biomacromolecules. Niosomes might be a significant breakthrough in personalized ocular therapy, in case they are optimized to be stable and reproducible.

7.2. Research Gaps and Challenges

Although these are encouraging results some limitations still exist. They are characterized by stability problems, including the vesicle aggregation, drug leakage, and poor shelf-life, which impede their high uptake. Additionally, even though the entrapment efficiencies and desirable release profiles are reported as high in laboratory-scale studies, the challenge of scaling up such technologies to commercial production is still a big challenge. Approval regulatory pathways of novel nanocarriers also complicate the process because the safety, reproducibility and long term tolerability need to be determined before use in patients. Notably, as of now, much of the evidence is based on in vitro and animal studies and only very few data points exist regarding large-scale clinical trials hence there is a lack of correspondence between laboratory potential and clinical performance. Also, possible eye irritation of surfactants, which is rather rare, casts doubt on the safety and acceptability of the patient.

7.3. Future Research Directions

To fill such gaps, specific and interdisciplinary research is needed. Future research opportunities are as follows:

- Production of hybrid solutions, in which niosomes will be used in conjunction with mucoadhesive polymers, hydrogels, or stimuli-responsive materials to enhance the precorneal retention, stability, and controlled release even further.
- Long and extensive clinical trials, which are required to help determine safety, efficacy, and patient acceptability in the real world.

- Efficiency in scale-up technologies including microfluidization or continuous manufacturing to achieve consistent production at industrial scale without affecting the quality.
- Investigation of gene and protein delivery, in which niosomes may be used as shields to help delicate macromolecules, and new possibilities of gene therapy and regenerative medicine of the eye open up.
- Toxicological investigations to determine ocular irritation, immunogenicity and systemic reactions of chronic exposure to tackle the issue of safety.

8. CONCLUSION

Niosomes have become an avenue of potential ocular delivery of drugs because of their capability to offer controlled and sustained release of the drug, high level of corneal penetration, and a high level of bioavailability than traditional formulations. Because of their versatility, they can be utilized to treat conditions affecting the posterior regions of the eye segment, such as retinal degeneration, glaucoma, ocular infections, and inflammation. By lowering the frequency of dose and minimizing systemic side effects, niosomes have the potential to address the most frustrating issues with patient compliance and response to treatment in chronic eye illnesses.

8.1.importance of the review:

The contribution of this review is that this paper summarizes the basics, methods of preparation and applications in therapeutics as well as comparative benefits of niosome-based systems. It highlights the implication of using niosomes as a cost-efficient and biocompatible substitute of liposomes and synthetic nanoparticles. Further, the review identifies the presence of opportunities and impediments, including the issue of stability, limited shelf-life and lack of clinical translation and therefore presents a fairly objective viewpoint that is necessary to support future research and industrial adoption.

8.2.Recommendations for future directions:

The continuous innovation is needed in several spheres in order to achieve the full clinical potential of niosomes. In future research, it is important to highlight:

- Hybrid systems (e.g. niosomes combined with mucoadhesive or stimuli-responsive polymers).
- Prolonged clinical trials to determine efficacy, safety and patient tolerability.
- Development of scalable and reproducible processes of industrial translation.
- Their application in the delivery of genes and peptides in new treatments to the eye.

To sum up, although there are still considerable obstacles to overcome, one must admit that niosomes have a transformative potential in ocular pharmacotherapy. As these systems continue to be interdisciplinary researched and regulated, they will be able to revolutionize ocular drug delivery, providing better therapeutic results, increased patient compliance and benefits with time, in the overall management of complicated eye disorders.

CONFLICT OF INTEREST

The author has no conflicts of interest regarding this investigation.

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