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NIOSOMES AS A NOVEL DRUG DELIVERY SYSTEM: CURRENT ADVANCES AND FUTURE PERSPECTIVES

V. Parthasarathi[1*], S. Yalisai Arasu[2]

[1]Associate Professor, Department of Pharmaceutics, G.P. Pharmacy College, Mandalavadi, Tirupattur, Tamil Nadu, India.

[2]B. Pharm Student, G.P. Pharmacy College, Mandalavadi, Tirupattur, Tamil Nadu, India.

***Corresponding Author: V. Parthasarathi**

Associate Professor, Department of Pharmaceutics, G.P. Pharmacy College, Mandalavadi, Tirupattur, Tamil Nadu, India. **DOI:** https://doi.org/10.5281/zenodo.20444143

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ABSTRACT

Niosomes are non-ionic surfactant-based vesicular drug delivery systems that have gained considerable attention in recent years due to their ability to improve the therapeutic efficacy and safety of various pharmaceutical agents. These vesicles are formed by the self-assembly of non-ionic surfactants in an aqueous medium, often stabilized with cholesterol, resulting in bilayer structures capable of encapsulating both hydrophilic and lipophilic drugs. Niosomes offer several advantages over conventional dosage forms and liposomal systems, including improved stability, controlled drug release, enhanced bioavailability, biocompatibility, and cost-effectiveness. The physicochemical properties of niosomes can be modified by altering formulation components, preparation methods, and surface characteristics, making them versatile carriers for targeted and sustained drug delivery. This review discusses the fundamental aspects of niosomes, including composition, types, methods of preparation, evaluation parameters, advantages, limitations, and factors affecting formulation. Furthermore, recent advancements such as nano-niosomes, proniosomes, ligand-targeted niosomes, and stimuli-responsive systems are critically summarized. The therapeutic applications of niosomes in cancer therapy, transdermal delivery, ocular delivery, oral drug delivery, vaccine delivery, and gene therapy are also highlighted. Despite certain limitations related to physical instability and scale-up challenges, ongoing research and advancements in nanotechnology continue to expand the potential of niosomal systems in modern pharmaceutical and biomedical applications.

KEYWORDS: Vesicular drug delivery system, Non-ionic surfactants, Targeted drug delivery, Nano-niosomes, Proniosomes, Controlled drug release, Drug encapsulation, Novel drug delivery system, Nanotechnology.

1. INTRODUCTION

The creation of effective drug delivery systems continues to be a key challenge in pharmaceutical sciences due to concerns such as low bioavailability, instability, quick degradation, and many therapeutic agents' lack of target specificity. Conventional dosage forms frequently fail to deliver medications at a controlled rate and to the intended location of action, resulting in lower therapeutic efficacy and higher side effects. As a result, the demand for novel drug delivery systems has increased dramatically in recent years. Vesicular drug delivery technologies, such as liposomes and niosomes, have received a lot of attention since they can encapsulate both hydrophilic and lipophilic medicines while also improving drug targeting. Niosomes have emerged as a possible alternative to liposomes due to their improved chemical stability, lower cost, and simplicity of storage. Niosomes are non-ionic surfactant-based vesicles generated by the self-assembly of surfactants in an aqueous media, often stabilized by cholesterol. This results in a bilayer structure capable of entrapping medicines of varied polarity.[1,2] Niosomes are structurally composed of a hydrophilic core surrounded by a non-polar bilayer, allowing them to encapsulate hydrophilic medicines in the aqueous region and lipophilic pharmaceuticals in the bilayer. This novel structure improves medication stability and enables for regulated and prolonged release of the agent. Furthermore, niosomes' physicochemical properties can be adjusted by changing formulation parameters such as

surfactant type, cholesterol level, and manufacturing process, making them highly adaptable carriers.[1] Niosomes are biodegradable, biocompatible, and largely non-toxic, making them appropriate for a variety of administration methods, including oral, topical, parenteral, and transdermal. They have demonstrated tremendous promise in targeted drug delivery, particularly for the treatment of cancer, infectious illnesses, and inflammatory disorders. Furthermore, breakthroughs in nanotechnology have led to the development of enhanced niosomal systems such as proniosomes and nano-niosomes, which improve their stability and therapeutic effectiveness.[3,4] Despite significant progress in the development of niosomal drug delivery systems, challenges such as vesicle aggregation, drug leakage, and scalability of production still limit their widespread clinical application. Recent research has focused on overcoming these limitations through the development of advanced systems such as nano-niosomes, ligand-targeted niosomes, and proniosomal formulations. In this context, the present review summarizes the fundamental aspects of niosomes, including their composition, preparation methods, and evaluation techniques, and critically discusses recent advancements, formulation challenges, and future perspectives.

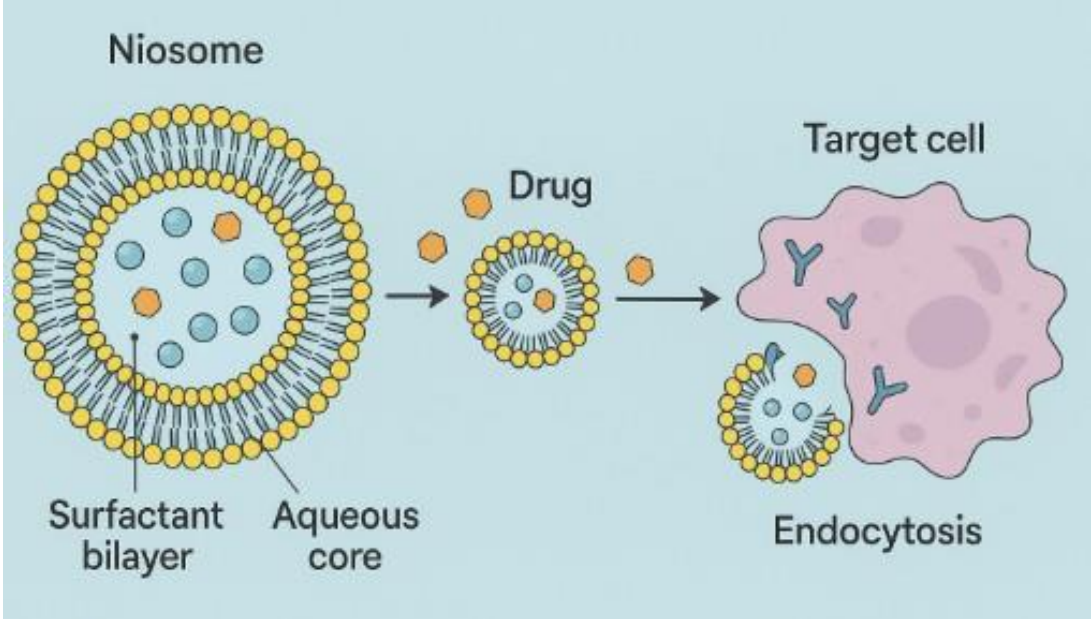

Figure 1: Schematic illustration of a niosome structure and its drug delivery process via endocytosis into a target cell.

2. COMPOSITION OF NIOSOMES

Niosomes are primarily composed of non-ionic surfactants, cholesterol, and sometimes charge-inducing agents. These components play a crucial role in determining the stability, entrapment efficiency, vesicle size, and drug release characteristics of the formulation. The selection of appropriate ingredients significantly influences the overall performance of niosomal drug delivery systems.

2.1 Non-ionic surfactants

Non-ionic surfactants are the fundamental building blocks of niosomes. They possess both hydrophilic and hydrophobic groups, enabling the formation of bilayer vesicles in aqueous environments. Commonly used surfactants include Spans (Span 20, Span 40, Span 60, Span 80), Tweens (Tween 20, Tween 40, Tween 60, Tween 80), and Brij series surfactants. Among these, Span 60 is widely preferred because of its high phase transition temperature and long alkyl chain, which contribute to better vesicle stability and higher drug entrapment efficiency.[5]

The hydrophilic-lipophilic balance (HLB) value of surfactants strongly affects vesicle formation. Surfactants with an HLB value between 4 and 8 are generally considered suitable for stable niosome preparation. Surfactants with extremely high hydrophilicity may fail to form stable bilayers, while highly lipophilic surfactants may reduce vesicle flexibility and drug loading capacity.[6]

2.2 Cholesterol

Cholesterol is an essential component incorporated into niosomal formulations to improve membrane rigidity and stability. It stabilizes the bilayer structure by reducing membrane permeability and preventing leakage of the entrapped drug. The presence of cholesterol also enhances the mechanical strength of vesicles and prolongs their shelf life. However, excessive cholesterol may reduce drug entrapment due to competition for space within the bilayer membrane.[7]

2.3 Charge-inducing agents

Charge-inducing agents are sometimes added to improve vesicle stability by preventing aggregation through

electrostatic repulsion. Negatively charged agents such as dicetyl phosphate and positively charged agents such as stearylamine are commonly employed. These agents increase the surface charge of vesicles, thereby minimizing fusion and improving dispersion stability.[8]

2.4 Hydration medium

The hydration medium used during niosome preparation also influences vesicle characteristics. Hydration is generally carried out using phosphate buffer saline (PBS), normal saline, or distilled water depending on the nature of the drug and intended application. Parameters such as pH and ionic strength of the hydration medium can affect vesicle size and drug entrapment efficiency.[9]

3. TYPES OF NIOSOMES

Niosomes can be classified based on vesicle size, lamellarity, and method of preparation.

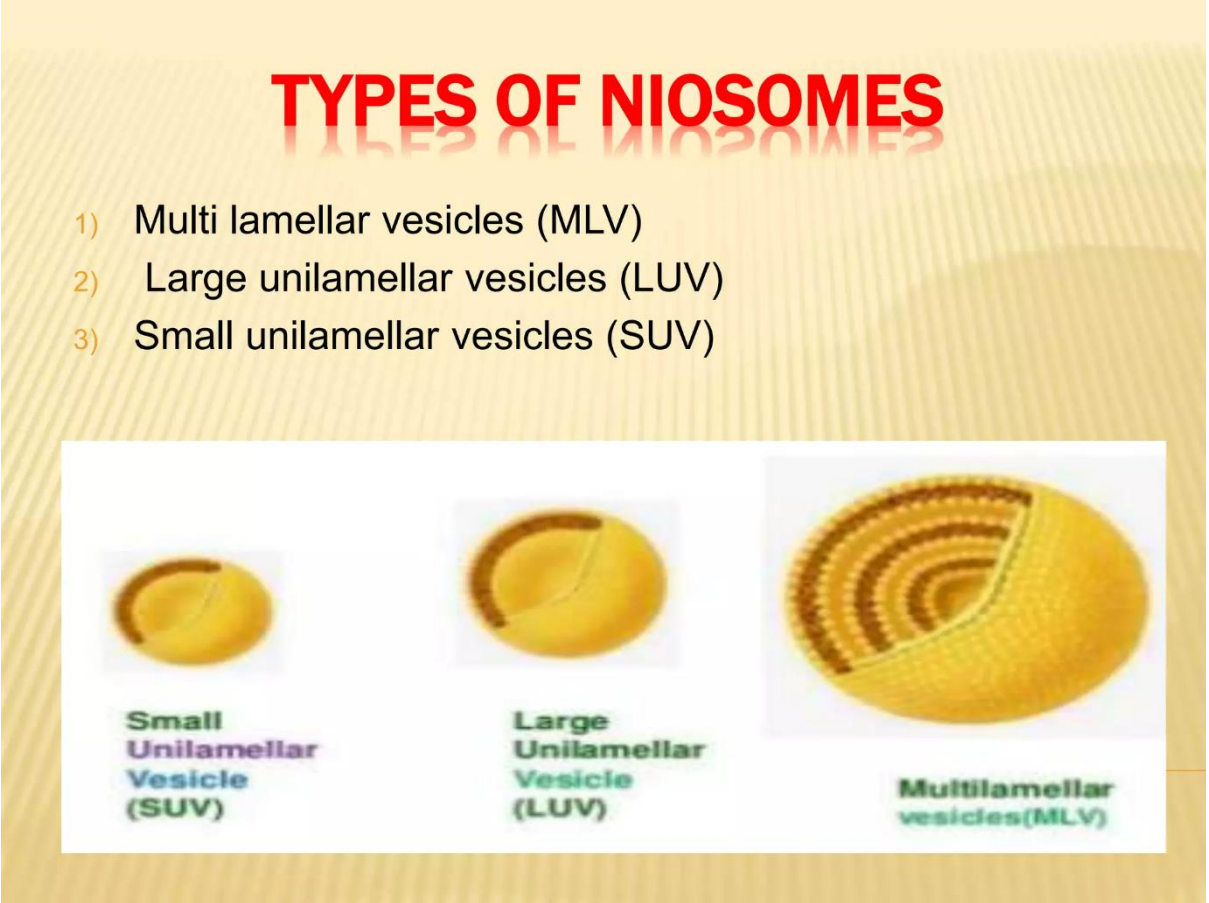

Figure 2: Types of niosomes.

3.1 Multilamellar Vesicles (MLVs)

Multilamellar vesicles consist of multiple concentric bilayers surrounding an aqueous core. These vesicles are relatively large in size and exhibit high drug loading capacity, particularly for lipophilic drugs. However, they may show limited uniformity in size distribution.[10]

3.2 Small Unilamellar Vesicles (SUVs)

Small unilamellar vesicles contain a single bilayer surrounding the aqueous core and usually range from 10–100 nm in diameter. They are generally produced by sonication or extrusion techniques and are suitable for targeted drug delivery applications due to their smaller particle size.[11]

3.3 Large Unilamellar Vesicles (LUVs)

Large unilamellar vesicles possess a single bilayer but larger internal aqueous space compared to SUVs. These vesicles are advantageous for encapsulating hydrophilic drugs because of their larger core volume.[12]

3.4 Proniosomes

Proniosomes are dry formulations that convert into niosomes upon hydration. They offer superior physical stability, ease of transportation, and reduced drug leakage during storage. Proniosomes have gained considerable attention for oral and transdermal drug delivery systems.[13]

3.5 Nano-Niosomes

Nano-niosomes are nanosized vesicular systems designed to enhance drug targeting and bioavailability. Due to their small size and large surface area, nano-niosomes improve cellular uptake and therapeutic efficacy, especially in cancer therapy and gene delivery applications.[14]

Table 1: Types of Niosomes, Size Range, and Description.

Type of Niosomes	Size Range	Simple Description
Small Unilamellar Niosomes (SUVs)	20–100 nm	Small vesicles with a single bilayer; suitable for rapid drug release.
Large Unilamellar Niosomes (LUVs)	100–500 nm	Large single-bilayer vesicles with high drug-loading capacity.
Multilamellar Niosomes (MLVs)	200 nm–5 µm	Vesicles with multiple bilayers; provide sustained and controlled drug release.
Deformable/Elastic Niosomes	100–300 nm	Flexible vesicles used mainly for transdermal drug delivery.
Charge-Modified Niosomes	100–400 nm	Surface-charged vesicles that improve stability and cellular interaction.
pH-Responsive Niosomes	100–300 nm	Vesicles designed to release drugs in acidic environments such as tumors.

4. METHODS OF PREPARATION OF NIOSOMES

Various techniques have been developed for the preparation of niosomes depending on the desired vesicle size, lamellarity, drug entrapment efficiency, and intended route of administration. The selection of an appropriate preparation method is critical for obtaining stable and reproducible formulations.

4.1 Thin Film Hydration Method (Hand Shaking Method)

The thin film hydration method is one of the most widely used techniques for preparing niosomes. In this method, non-ionic surfactants and cholesterol are dissolved in an organic solvent such as chloroform or methanol. The solvent is then evaporated under reduced pressure using a rotary evaporator to form a thin lipid film on the wall of a round-bottom flask. Hydration of the dried film with an aqueous phase containing the drug leads to the formation of multilamellar vesicles.[15]

This method is simple and suitable for both hydrophilic and lipophilic drugs. However, it may produce vesicles with wide size distribution, requiring further size reduction techniques such as sonication or extrusion.

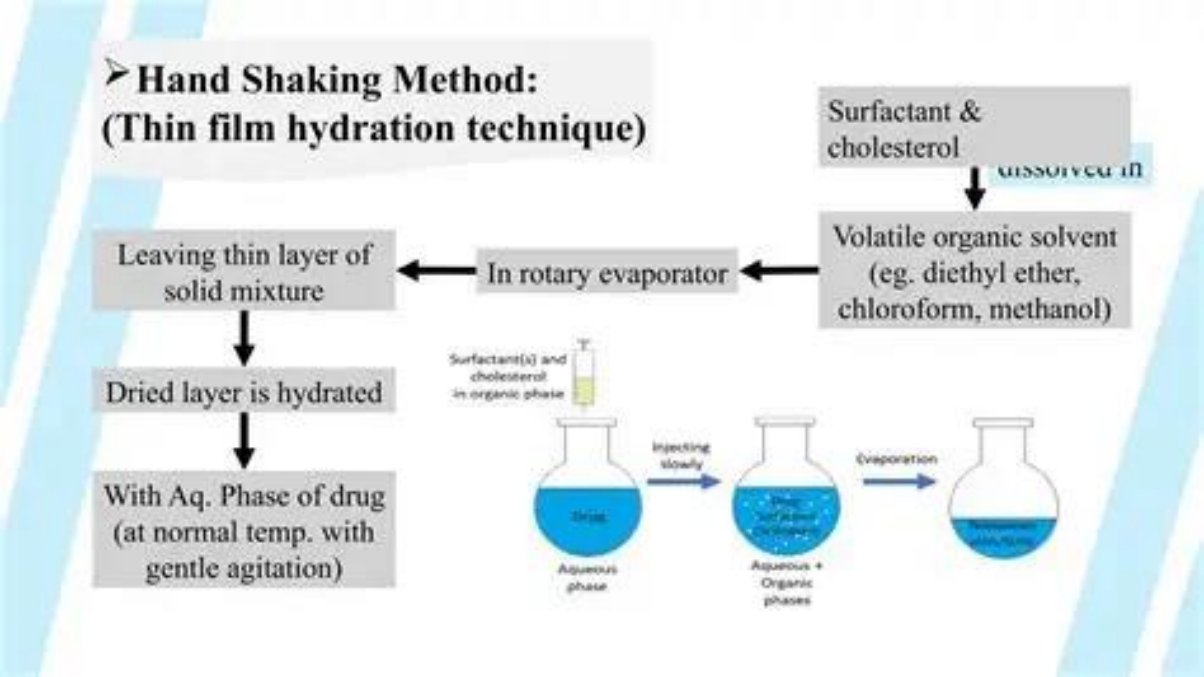

Figure 3: Thin Film Hydration Method (Hand Shaking Method).

4.2 Reverse Phase Evaporation Method

In the reverse phase evaporation method, surfactants and cholesterol are dissolved in an organic solvent, followed by the addition of an aqueous drug solution to form a water-in-oil emulsion. Upon removal of the organic solvent under reduced pressure, the emulsion collapses and forms niosomal vesicles with high aqueous core volume.[16]

This method generally provides higher drug entrapment efficiency for hydrophilic drugs compared to conventional thin film hydration techniques.

4.3 Ether Injection Method

In this technique, surfactant and cholesterol dissolved in diethyl ether are slowly injected into a warm aqueous phase containing the drug. The ether vaporizes

immediately, leading to the formation of unilamellar vesicles.[17]

The method is relatively simple and produces vesicles with uniform size distribution. However, the use of organic solvents and elevated temperature may not be suitable for thermolabile drugs.

4.4 Sonication Method

Sonication is commonly employed to reduce the size of multilamellar vesicles into small unilamellar vesicles. Probe sonicators or bath sonicators are used to apply ultrasonic energy, resulting in smaller vesicles with narrow size distribution.[18]

Although sonication improves vesicle uniformity, prolonged exposure may cause drug degradation or contamination from the sonicator probe.

4.5 Microfluidization Method

Microfluidization involves the interaction of two fluid streams at high velocity within a microchannel chamber. The collision of streams produces vesicles with uniform size and high reproducibility.[19]

This method is particularly useful for large-scale production because it provides better control over particle size and distribution.

4.6 Bubble Method

The bubble method is a solvent-free technique used for the preparation of niosomes. In this method, surfactants and cholesterol are dispersed in an aqueous medium at elevated temperature, followed by bubbling nitrogen gas through the dispersion to form vesicles.[20]

The absence of organic solvents makes this method environmentally friendly and suitable for sensitive pharmaceutical compounds.

5. FACTORS AFFECTING NIOSOME FORMULATION

Several formulation and process variables influence the physicochemical properties and therapeutic performance of niosomes.

5.1 Nature of Surfactant

The type of surfactant significantly affects vesicle formation, entrapment efficiency, and stability. Surfactants with higher phase transition temperature generally produce more stable vesicles with reduced permeability.[21]

5.2 Cholesterol Content

Cholesterol concentration influences membrane rigidity and permeability. An optimum amount is necessary to stabilize the bilayer structure; excessive cholesterol may reduce drug entrapment efficiency.[22]

5.3 Hydration Temperature

Hydration temperature should usually be maintained above the phase transition temperature of the surfactant to facilitate proper bilayer formation. Inadequate temperature may result in incomplete hydration and unstable vesicles.[23]

5.4 Drug Characteristics

The physicochemical properties of the drug, including solubility, molecular weight, and polarity, determine its localization within the vesicle and influence entrapment efficiency.[24]

5.5 Method of Preparation

Different preparation methods yield vesicles with varying sizes, lamellarity, and encapsulation efficiency. Therefore, the choice of method directly impacts formulation performance.[25]

6. EVALUATION PARAMETERS OF NIOSOMES

Evaluation of niosomal formulations is essential to determine their physicochemical characteristics, stability, and therapeutic performance. Various analytical techniques are employed to assess vesicle morphology, size distribution, drug entrapment efficiency, and in vitro drug release behavior.

6.1 Vesicle Size and Size Distribution

Vesicle size is an important parameter influencing drug release, biodistribution, and stability of niosomes. Particle size analysis is commonly performed using dynamic light scattering (DLS), laser diffraction, or optical microscopy. Smaller vesicles generally exhibit enhanced cellular uptake and improved drug penetration.[26]

Polydispersity index (PDI) is used to evaluate size uniformity. A lower PDI value indicates a homogeneous vesicle population.

6.2 Morphological Characterization

Morphology and surface characteristics of niosomes are examined using microscopic techniques such as transmission electron microscopy (TEM), scanning electron microscopy (SEM), and atomic force microscopy (AFM). These methods provide information regarding vesicle shape, surface smoothness, and lamellarity.[27]

6.3 Entrapment Efficiency

Entrapment efficiency refers to the percentage of drug successfully encapsulated within the vesicles compared to the total amount of drug used during formulation. It is generally determined by separating unentrapped drug through centrifugation, dialysis, or gel filtration techniques.[28]

The entrapment efficiency can be calculated using the following equation.

$$\text{Entrapment Efficiency (\%)} = \frac{\text{Entrapped Drug}}{\text{Total Drug}} \times 100$$

Higher entrapment efficiency indicates better drug loading capacity and improved formulation performance.

6.4 Zeta Potential

Zeta potential measures the surface charge of vesicles and predicts formulation stability. High positive or negative zeta potential values generally indicate greater electrostatic repulsion between vesicles, thereby reducing aggregation and improving stability.[29]

6.5 In Vitro Drug Release Studies

In vitro drug release studies are conducted to evaluate the release profile of the encapsulated drug from niosomes. Commonly used methods include dialysis membrane technique, Franz diffusion cell method, and diffusion chambers.[30]

Controlled and sustained drug release from niosomes enhances therapeutic efficacy while minimizing adverse effects.

6.6 Stability Studies

Stability studies assess the physical and chemical stability of niosomal formulations under different storage conditions. Parameters such as vesicle size, drug leakage, appearance, and entrapment efficiency are monitored over time.[31]

Storage at refrigerated temperature is often preferred to minimize vesicle aggregation and drug leakage.

7. APPLICATIONS OF NIOSOMES

Niosomes have attracted considerable attention because of their ability to improve drug bioavailability, reduce toxicity, and provide targeted drug delivery. Their versatility allows application in several therapeutic areas.

7.1 Targeted Drug Delivery

Niosomes can selectively deliver drugs to specific tissues or organs, thereby reducing systemic toxicity and improving therapeutic effectiveness. Surface modification with ligands or antibodies further enhances site-specific targeting.[32]

7.2 Cancer Therapy

Niosomes are extensively investigated for anticancer drug delivery because they improve drug accumulation at tumor sites and reduce adverse effects associated with conventional chemotherapy. Drugs such as doxorubicin, methotrexate, and paclitaxel have been successfully incorporated into niosomal systems.[33]

7.3 Transdermal Drug Delivery

Niosomes enhance skin penetration of drugs by interacting with stratum corneum lipids and improving drug permeation. They are widely used in transdermal formulations for anti-inflammatory, antifungal, and analgesic agents.[34]

7.4 Oral Drug Delivery

Niosomes protect drugs from degradation in the gastrointestinal tract and improve oral bioavailability. They are particularly useful for poorly soluble and peptide-based drugs.[35]

7.5 Ocular Drug Delivery

Niosomal formulations prolong drug residence time in the eye and improve ocular bioavailability. They reduce frequent dosing requirements and enhance patient compliance.[36]

7.6 Vaccine and Gene Delivery

Niosomes are also employed as carriers for vaccines and genetic materials due to their biocompatibility and ability to enhance immune responses. They can effectively deliver DNA, RNA, and protein antigens to target cells.[37]

8. ADVANTAGES OF NIOSOMES

Niosomes possess several advantages over conventional drug delivery systems, making them promising carriers for pharmaceutical applications. Their unique vesicular structure enhances therapeutic effectiveness while minimizing adverse effects.

8.1 Improved Drug Stability

Niosomes protect encapsulated drugs from chemical and enzymatic degradation. The bilayer membrane acts as a barrier against external environmental factors such as pH, oxidation, and hydrolysis, thereby improving drug stability during storage and administration.[38]

8.2 Controlled and Sustained Drug Release

Niosomal systems provide controlled and prolonged drug release, maintaining therapeutic drug concentrations for extended periods. This reduces dosing frequency and improves patient compliance.[39]

8.3 Enhanced Bioavailability

Encapsulation of drugs within niosomes improves absorption and bioavailability, especially for poorly water-soluble and poorly permeable drugs. Niosomes enhance drug transport across biological membranes due to their amphiphilic nature.[40]

8.4 Targeted Drug Delivery

Niosomes can selectively accumulate at target tissues, reducing systemic toxicity and improving therapeutic efficacy. Surface modification with ligands enables active targeting toward specific cells or receptors.[41]

8.5 Biocompatibility and Low Toxicity

Niosomes are composed mainly of non-ionic surfactants, which are generally biodegradable, biocompatible, and less toxic compared to ionic surfactants. This property makes them suitable for repeated administration.[42]

8.6 Versatility in Drug Encapsulation
Niosomes can encapsulate both hydrophilic and lipophilic drugs. Hydrophilic drugs are entrapped within the aqueous core, while lipophilic drugs are incorporated into the bilayer membrane.[43]

8.7 Ease of Storage and Handling
Compared with liposomes, niosomes exhibit greater chemical stability and require less stringent storage conditions. Proniosomal formulations further improve shelf life and transportation convenience.[44]

9. LIMITATIONS OF NIOSOMES
Despite their numerous advantages, niosomes also possess certain limitations that may restrict their large-scale clinical applications.

9.1 Physical Instability
Niosomal dispersions may undergo aggregation, fusion, sedimentation, or leakage of entrapped drug during storage. These issues can reduce formulation stability and therapeutic performance.[45]

9.2 Drug Leakage
Entrapped drugs may leak from vesicles over time due to membrane instability or improper storage conditions, resulting in reduced drug retention capacity.[46]

9.3 Limited Shelf Life
Although niosomes are more stable than liposomes, aqueous niosomal dispersions may still exhibit limited shelf life because of vesicle degradation and physicochemical instability.[47]

9.4 Scale-Up Challenges
Large-scale manufacturing of niosomes with uniform vesicle size and reproducibility remains challenging. Variability during industrial production may affect formulation quality and therapeutic consistency.[48]

9.5 High Production Cost for Advanced Systems
Advanced niosomal systems such as ligand-targeted niosomes, nano-niosomes, and stealth niosomes may involve sophisticated preparation methods and expensive materials, increasing production costs.[49]

10. RECENT ADVANCES IN NIOSOMAL DRUG DELIVERY
Recent developments in nanotechnology and pharmaceutical sciences have significantly improved the effectiveness of niosomal formulations. Several advanced vesicular systems have been developed to overcome conventional limitations.

10.1 Nano-Niosomes
Nano-niosomes are nanosized vesicles designed to enhance drug targeting, cellular uptake, and bioavailability. Their smaller size improves penetration through biological barriers and increases circulation time in the bloodstream.[50]

10.2 Ligand-Targeted Niosomes
Ligand-targeted niosomes are surface-modified vesicles containing antibodies, peptides, or specific ligands that selectively bind to receptors present on target cells. These systems improve site-specific drug delivery and reduce off-target toxicity.[51]

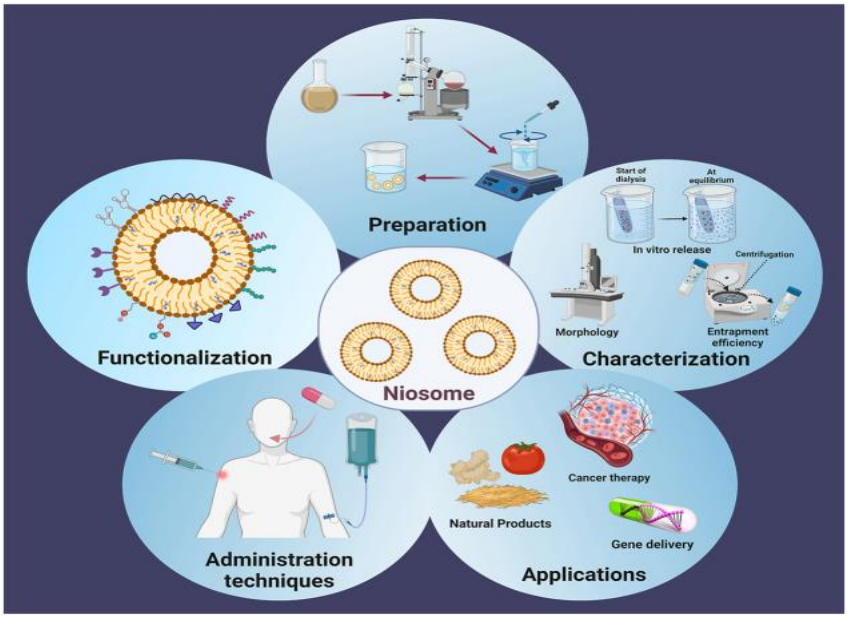

Figure 4: Schematic representation of niosomes showing preparation methods, characterization techniques, functionalization strategies, administration routes, and therapeutic applications.

10.3 Proniosomes
Proniosomes are dry free-flowing formulations that form niosomes upon hydration. They exhibit superior stability, reduced aggregation, and improved shelf life compared to conventional aqueous niosomal dispersions.[52]

10.4 Stimuli-Responsive Niosomes

Stimuli-responsive niosomes release drugs in response to specific environmental triggers such as pH, temperature, magnetic field, or enzymes. These systems provide controlled and site-specific drug release.[53]

10.5 Niosomes in Gene Delivery

Modern niosomal systems are increasingly explored for gene delivery applications. Cationic niosomes facilitate the transport of nucleic acids such as DNA, siRNA, and mRNA into target cells with reduced toxicity.[54]

11. REFERENCES

1. Bautista-Solano, A.A., Dávila-Ortiz, G., Perea-Flores, M.D., & Martínez-Ayala, A.L. (2025). A Comprehensive Review of Niosomes: Composition, Structure, Formation, Characterization, and Applications in Bioactive Molecule Delivery Systems. Molecules, 30.
2. Sharma D, Ali AAE, Aate JR. Niosomes as novel drug delivery system: review article. PharmaTutor, 2018; 6(3): 58–65. doi: 10.29161/PT.v6.i3.2018.58
3. Bhardwaj P, Tripathi P, Gupta R, Pandey S. Niosomes: a review on niosomal research in the last decade. Journal of Drug Delivery Science and Technology, 2020; 56: 101581.
4. Mawazi SM, Ge Y, Widodo RT. Niosome preparation techniques and structure—An illustrated review. Pharmaceutics, 2025 Jan 6; 17(1): 67.
5. Uchegbu IF, Vyas SP. Non-ionic surfactantbased vesicles (niosomes) in drug delivery. Int J Pharm, 1998; 172(1-2): 33-70.
6. Moghassemi S, Hadjizadeh A. Nano-niosomes as nanoscale drug delivery systems: an illustrated review. J Control Release, 2014; 185: 22-36.
7. Manosroi A, Wongtrakul P, Manosroi J, et al. Characterization of vesicles prepared with various non-ionic surfactants mixed with cholesterol. Colloids Surf B Biointerfaces, 2003; 30(1-2): 129-138.
8. Baillie AJ, Florence AT, Hume LR, Muirhead GT, Rogerson A. The preparation and properties of niosomes—non-ionic surfactant vesicles. J Pharm Pharmacol, 1985; 37(12): 863-868.
9. Kazi KM, Mandal AS, Biswas N, et al. Niosome: a future of targeted drug delivery systems. J Adv Pharm Technol Res, 2010; 1(4): 374-380.
10. Yoshioka T, Sternberg B, Florence AT. Preparation and properties of vesicles (niosomes) of sorbitan monoesters. Int J Pharm, 1994; 105(1): 1-6.
11. Hunter CA, Dolan TF, Coombs GH, Baillie AJ. Vesicular systems (niosomes and liposomes) for delivery of sodium stibogluconate in experimental murine visceral leishmaniasis. J Pharm Pharmacol, 1988; 40(3): 161-165.
12. Schreier H, Bouwstra J. Liposomes and niosomes as topical drug carriers: dermal and transdermal drug delivery. J Control Release, 1994; 30(1): 1-15.
13. Hu C, Rhodes DG. Proniosomes: a novel drug carrier preparation. Int J Pharm, 1999; 185(1): 23-35.
14. Pardakhty A, Moazeni E, Varshosaz J, Hajhashemi VI, Rouholamini A. In vitro study of polyoxyethylene alkyl ether niosomes for delivery of insulin. Int J Pharm, 2007; 328(2): 130-141.
15. Bangham AD, Standish MM, Watkins JC. Diffusion of univalent ions across the lamellae of swollen phospholipids. J Mol Biol, 1965; 13(1): 238-252.
16. Szoka F Jr, Papahadjopoulos D. Procedure for preparation of liposomes with large internal aqueous space and high capture by reverse-phase evaporation. Proc Natl Acad Sci U S A, 1978; 75(9): 4194-4198.
17. Devaraj GN, Parakh SR, Devraj R, Apte SS, Rao BR, Rambhau D. Release studies on niosomes containing fatty alcohols as bilayer stabilizers instead of cholesterol. J Colloid Interface Sci, 2002; 251(2): 360-365.
18. Aziz DE, Abdelbary AA, Elassasy AI. Investigating superiority of novel bilosomes over niosomes in transdermal delivery of diacerein: characterization, in vitro and in vivo studies. J Liposome Res, 2019; 29(1): 73-85.
19. Kumar GP, Rajeshwarrao P. Nonionic surfactant vesicular systems for effective drug delivery—an overview. Acta Pharm Sin B, 2011; 1(4): 208-219.
20. Chauhan S, Luorence MJ. The preparation of polyoxyethylene-containing non-ionic surfactant vesicles. J Pharm Pharmacol, 1989; 41(1): 6-10.
21. Ruckmani K, Sankar V. Formulation and optimization of zidovudine niosomes. AAPS PharmSciTech, 2010; 11(3): 1119-1127.
22. Balakrishnan P, Shanmugam S, Lee WS, et al. Formulation and in vitro assessment of minoxidil niosomes for enhanced skin delivery. Int J Pharm, 2009; 377(1-2): 1-8.
23. Junyaprasert VB, Teeranachaideekul V, Supaperm T. Effect of charged and non-ionic membrane additives on physicochemical properties and stability of niosomes. AAPS PharmSciTech, 2008; 9(3): 851-859.
24. Carafa M, Santucci E, Lucania G. Lidocaine-loaded non-ionic surfactant vesicles: characterization and in vitro permeation studies. Int J Pharm, 2002; 231(1): 21-32.
25. Marianecci C, Di Marzio L, Rinaldi F, et al. Niosomes from 80s to present: the state of the art. Adv Colloid Interface Sci, 2014; 205: 187-206.
26. Shaker DS, Ishak RA, Ghoneim A, Elhuoni MA. Nanoemulsion: a review on mechanisms for the transdermal delivery of hydrophobic and hydrophilic drugs. Sci Pharm, 2019; 87(3): 17.
27. Pardakhty A, Varshosaz J, Rouholamini A. In vitro study of polyoxyethylene alkyl ether niosomes for delivery of insulin. Int J Pharm, 2007; 328(2): 130-141.
28. Mokhtar M, Sammour OA, Hammad MA, Megrab NA. Effect of some formulation parameters on

flurbiprofen encapsulation and release rates of niosomes prepared from proniosomes. Int J Pharm, 2008; 361(1-2): 104-111.
29. Hao Y, Zhao F, Li N, Yang Y, Li K. Studies on a high encapsulation of colchicine by a niosome system. Int J Pharm, 2002; 244(1-2): 73-80.
30. Aggarwal D, Kaur IP. Improved pharmacodynamics of timolol maleate from a mucoadhesive niosomal ophthalmic drug delivery system. Int J Pharm, 2005; 290(1-2): 155-159.
31. Tavano L, Muzzalupo R, Picci N, de Cindio B. Coenzyme Q10 and hydroxytyrosol-enriched niosomes as effective formulations for skin protection against oxidative stress. Colloids Surf B Biointerfaces, 2014; 118: 1-7.
32. Singh A, Kumar P, Tiwari AK, et al. Niosomes: a future aspect for targeted drug delivery systems. Int J Pharm Sci Drug Res, 2017; 9(2): 41-48.
33. Azmin MN, Florence AT, Handjani-Vila RM, Stuart JF, Vanlerberghe G, Whittaker JS. The effect of non-ionic surfactant vesicle (niosome) entrapment on the absorption and distribution of methotrexate in mice. J Pharm Pharmacol, 1985; 37(4): 237-242.
34. Manosroi A, Jantrawut P, Manosroi J. Anti-inflammatory activity of gel containing novel elastic niosomes entrapped with diclofenac diethylammonium. Int J Pharm, 2008; 360(1-2): 156-163.
35. Raja Naresh RA, Chandrashekhar G, Pillai GK, Udupa N. Antiinflammatory activity of niosome encapsulated diclofenac sodium with Tween-85 in arthritic rats. Indian J Pharmacol, 1994; 26(1): 46-48.
36. Abdelkader H, Ismail S, Kamal A, Alany RG. Design and evaluation of controlled-release niosomes and discomes for naltrexone hydrochloride ocular delivery. J Pharm Sci, 2011; 100(5): 1833-1846.
37. Moghassemi S, Hadjizadeh A. Nano-niosomes as nanoscale drug delivery systems: an illustrated review. J Control Release, 2014; 185: 22-36.
38. Hunter CA. Vesicular systems (niosomes and liposomes) for delivery of sodium stibogluconate in experimental murine visceral leishmaniasis. J Pharm Pharmacol, 1988; 40(3): 161-165.
39. Khandare JN, Madhavi G, Tamhankar BM. Niosomes novel drug delivery system. East Pharm, 1994; 37: 61-64.
40. Udupa N. Niosomes as drug carriers. In: Jain NK, editor. Controlled and Novel Drug Delivery. New Delhi: CBS Publishers, 2002; 292-304.
41. Vyas SP, Khar RK. Targeted and Controlled Drug Delivery: Novel Carrier Systems. 1st ed. New Delhi: CBS Publishers, 2004.
42. Florence AT, Attwood D. Physicochemical Principles of Pharmacy. 5th ed. London: Pharmaceutical Press, 2011.
43. Malhotra M, Jain NK. Niosomes as drug carriers. Indian Drugs, 1994; 31(3): 81-86.
44. Solanki AB, Parikh JR, Parikh RH. Formulation and optimization of piroxicam proniosomes by 3-factor, 3-level Box-Behnken design. AAPS PharmSciTech, 2007; 8(4): E1-E7.
45. Alsarra IA, Bosela AA, Ahmed SM, Mahrous GM. Proniosomes as a drug carrier for transdermal delivery of ketorolac. Eur J Pharm Biopharm, 2005; 59(3): 485-490.
46. Yoshioka T, Sternberg B, Florence AT. Preparation and properties of vesicles (niosomes) of sorbitan monoesters. Int J Pharm, 1994; 105(1): 1-6.
47. Baillie AJ, Coombs GH, Dolan TF, Laurie J. Non-ionic surfactant vesicles, niosomes, as delivery systems for the antileishmanial drug sodium stibogluconate. J Pharm Pharmacol, 1986; 38(7): 502-505.
48. Marianecci C, Di Marzio L, Rinaldi F, et al. Niosomes from 80s to present: the state of the art. Adv Colloid Interface Sci, 2014; 205: 187-206.
49. Moghassemi S, Hadjizadeh A. Nano-niosomes as nanoscale drug delivery systems: an illustrated review. J Control Release, 2014; 185: 22-36.
50. Kazi KM, Mandal AS, Biswas N, et al. Niosome: a future of targeted drug delivery systems. J Adv Pharm Technol Res, 2010; 1(4): 374-380.
51. Shreya AB, Bajpai M, Khan S, et al. Recent advances in niosome-based drug delivery systems. Expert Opin Drug Deliv, 2018; 15(12): 1283-1298.
52. Hu C, Rhodes DG. Proniosomes: a novel drug carrier preparation. Int J Pharm, 1999; 185(1): 23-35.
53. Muzzalupo R, Tavano L. Niosomal drug delivery for transdermal targeting: recent advances. Res Rep Transdermal Drug Deliv, 2015; 4: 23-33.
54. Ge X, Wei M, He S, Yuan WE. Advances of non-ionic surfactant vesicles (niosomes) and their application in drug delivery. Pharmaceutics, 2019; 11(2): 55.