Review Article

Dendrosome: A Comprehensive Review of Hybrid Lipid-Dendrimer Nanocarriers for Drug and Gene Delivery.

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ABSTRACT

Dendrosomes are innovative hybrid nanocarriers created from lipids and dendrimers that have gained considerable attention due to their potential in drug delivery and gene therapy. By merging the beneficial characteristics of liposomes—such as biocompatibility, biodegradability, and the capacity to encapsulate both hydrophilic and hydrophobic agents—with the precise structural control, nanoscale dimensions, and multifunctional surface chemistry of dendrimers, dendrosomes provide a flexible and novel platform for therapeutic applications. Among various dendrimers, polyamidoamine (PAMAM) has been the most thoroughly researched because of its well-defined structure, a high density of terminal groups, and innate ability to condense genetic material, thereby promoting effective cellular uptake and transfection. Multiple preparation techniques, including thin-film hydration, ethanol injection, reverse phase evaporation, microfluidics, sonication, and extrusion, have been developed to optimize the size, shape, and encapsulation efficiency of dendrosomes. These techniques enable the customization of properties for targeted delivery and controlled drug release. Evaluation parameters such as particle size distribution, zeta potential, morphology, entrapment efficiency, cytotoxicity, cellular uptake, and drug release studies also validate their safety and effectiveness. Dendrosomes have demonstrated remarkable potential in biomedical applications. In cancer therapy, they enhance the solubility and bioavailability of poorly soluble drugs, provide controlled release, and enable ligand-mediated targeting to tumor cells while minimizing toxicity to healthy tissues. In gene therapy, they serve as safe and efficient non-viral vectors that protect nucleic acids from degradation and significantly improve transfection efficiency. Furthermore, their application in vaccine delivery shows promise, with dendrosomes serving as adjuvants that promote prolonged antigen release and stimulate immune responses. In conclusion, dendrosomes represent a biocompatible, stable, and cost-effective delivery system, establishing themselves as next-generation nanocarriers in the field of nanomedicine. The review highlights their design, preparation techniques, evaluation methods, and diverse therapeutic uses, underscoring their significance in the advancement of modern drug and gene delivery.

Keywords: Dendrosomes, Dendrimers, PAMAM, Drug Delivery, Gene Therapy, Biocompatibility, Targeted Delivery.

INTRODUCTION

Liposomes, polymeric micelles, and dendrimers are the most widely studied drug delivery systems at the nano scale (nano DDS) and are considered the first generation. Liposomes are lipid-based vesicles that provide biocompatibility, biodegradability and can transport hydrophilic drugs in aqueous core, and hydrophobic drug in lipid bilayer. Dendrimers are highly branched polymeric molecules with consistent structural characteristics, restricted size distribution, and easy derivatisation via peripheral functional groups.[1]

Dendrosomes, complex, self-assembling, multivalent molecules, have emerged as versatile tools in nanomedicine and materials science, exhibiting a unique architectural design inspired by the branching patterns of dendrimers and the encapsulation capabilities of liposomes [2]. The conceptual genesis of dendrosomes can be traced back to the convergence of research in dendritic structures and vesicular delivery systems, with the goal of creating a hybrid nanocarrier that combines the advantages of both approaches [3]. The architecture of dendrosomes was inspired by dendrimers, which have a tree-like structure and can be precisely controlled in size, shape, and surface functioning. These synthetic constructs provide a platform for multivalent presentation of ligands, drugs, or imaging agents, effectively reorganizing their interaction at the biological target while potentially enhancing therapeutic efficacy [4]. Liposomes are spherical vesicles consisting of lipid-bilayer membranes that can entrap a host of materials, including drugs, proteins, and nucleic acids[5]. Biocompatibility, reduced cytotoxicity, customised size, composition, lamellarity, and surface charge distinguish them from standard drug delivery devices. [6].

The first generation of dendrosomes involved the integration of dendrimers within liposomal structures, either by incorporating dendrimers into the lipid bilayer or by encapsulating them within the aqueous core of the liposome.

DENDROSOMES

Dendrosomes are supramolecular structures formed by self-assembling amphiphilic block copolymers in aqueous solutions. Dendritic polymers are present in at least one block of these amphiphilic copolymer systems. They feature a spherical topology and a hollow shape with a hydrophilic core surrounded by a bilayer membrane.[7] These supramolecular structures can encapsulate and transport hydrophobic and hydrophilic medicinal medicines as well as tiny guest molecules. Dendrosomes have hydrophilic cores

and hydrophobic membranes, allowing hydrophilic and hydrophobic guest molecules to enclose inside them. [8]

Dendrosomes were initially used for gene delivery, but have since been used for medication delivery as well. Liposomal nanocarriers encapsulate drug-loaded dendrimers for prolonged release. Dendrosomes typically have a dendrimer core and a liposomal membrane around them. This is a hybrid carrier technology that uses liposomes to encapsulate dendrimers.[9]

DENDRIMERS

Dendrimers are three-dimensional polymers that are extremely branched and reactive. All linkages originate from a central core. The name 'dendrimer' comes from the Greek word 'dendron' (tree) and the suffix'mer' (from meros, meaning smallest repeating unit). Dendrimers have recently received significant interest from biological researchers. Dendrimers have advantages over other polymers for drug delivery due to their nanoscopic size, highly controlled molecular weight, huge number of accessible terminal functional groups, and ability to encapsulate a guest molecule in internal cavities. Dendrimers' nanoscale size allows them to bypass the body's reticuloendothelial system (RES) and play a crucial role in intracellular drug delivery[10]. The amine-terminated dendrimers' inherent cationic charge and spherical form make them ideal for delivering genes and immunogens.

Polyamidoamine (PAMAM) dendrimers are globular and extensively branching, with main amino groups located on the periphery. PAMAM dendrimers have a limited positive charge, which allows for DNA condensation and transfection. This is due to the presence of certain main amino groups. These cationic gene delivery vectors bind to DNA and create a stable complex through electrostatic interactions. The dendrimer-DNA complex's net positive charge allows it to permeate the cell membrane and release DNA, resulting in gene expression.[8]

Dendrimers have several applications.

Dendrimers are widely categorised into two types: medicinal and nonmedical applications**.**

1. Medical Uses

(1) A biomedical research study. Dendrimers, similar to proteins, enzymes, and viruses, are commonly utilised in biomedicine to target cells and bind to host dendrimeric cells, such as poly(amidoamine) dendrimers [8].

(2) Resonance of magnetic fields. Dendrimers are commonly employed in magnetic resonance to increase picture contrast. Metallic dendrimers are utilised to make magnetic resonance imaging contrast agents [11].

(3) The term bio mimics. Dendrimers imitate many biomolecules and generate a microenvironment [12].

2. Increased solubility. Dendrimers contribute to enhancing the solubility profile of poorly and sparingly soluble medicines, resulting in higher drug bioavailability [13].

3. Improved stability. The dendritic formulation stabilises substances by creating internal chambers for neutral molecules and ions to avoid deterioration.

4. Focused Delivery. Dendrimers also help in site-specific targeted medication delivery by allowing ligands to bind to the dendrimer surface.

5. Formulations' dummy and carrier. Dendrimer molecules may pass cell membranes due to their homogeneous size, which aids in numerous pharmacological actions [15].

6. nanoparticles. Poly(amidoamine) (PAMAM) dendrimers are employed as nanoparticles because they have a tertiary amine group at their branching point. Dendrimers' aqueous solution contains metal ions, which form a complex with the tertiary amines' single electron pair. The ions are subsequently reduced to zero-valent state, forming nanoparticles that are contained within the dendrimer [14].

7. Nanodrugs. Various dendrimeric formulations, such as polylysine (PPL) dendrimers containing sulfonated naphthyl groups, were employed as nanodrugs to treat a variety of disorders. PPL dendrimers containing tertiary alkylammonium groups have antibacterial properties, whereas chitosan dendrimer hybrids are also employed.[8]

CLASSIFICATION OF DENDRIMERS

The dendrimers are classified based on

- **Property**
- **Structure**

Based on properties

Dendrimers have distinct physical and chemical characteristics, yet have a similar geometric structure. The physical character of branching elements and surface groups is determined completely by their chemical properties. The many dendrimer families are outlined below:

Hydrophilic dendrimers

Particularly PAMAM (polyamidoamine) dendrimers, are the most widely synthesized and marketed. Their synthesis begins with a Michael addition reaction between ethylenediamine and methyl acrylate, forming branched intermediates. Further reactions with ethanolamine and ethylenediamine yield dendrimers with −OH and −NH surface groups, while hydrolysis produces anionic dendrimers with −COOH groups. As generations increase, steric hindrance (dense packing effect) reduces yield due to overcrowded branches.[18]

These dendrimers are efficient drug transporters due to their high water solubility, varied surface groups, and distinct structures. They are commonly offered as methanol solutions. Starburst® is a subclass that has tris-aminoethylene-imine core. Fréchet-type dendrimers, created by Hawker and Fréchet, have −COOH groups that improve solubility and anchoring**. PAMAMOS**, the first silicon-containing dendrimer, features hydrophilic PAMAM

interiors and hydrophobic organosilicon exteriors; **SARSOX** is a marketed example. **PPI dendrimers** contain polyalkyl amine end groups and trispropylene amine cores, available up to generation 5 (G5), and sold as **Astromol**.[19]

Biodegradable dendrimers

were developed to achieve high tissue deposition and allow rapid urinary elimination of their fragments, reducing nonspecific toxicity. They typically incorporate ester bonds that degrade via chemical or enzymatic cleavage under physiological conditions. Factors affecting their breakdown include bond type, monomer lipophilicity, dendrimer size, and sensitivity to internal and surface structures. Polyester dendrimers are biocompatible and biodegradable, making them popular in anticancer and gene therapy applications. However, nonspecific hydrolysis and delayed degradation have led to current research into designing dendrimers with precise, geographically and temporally regulated breakdown. [20]

Amino acid (AA)-based dendrimers

are synthesized by integrating blocks with properties like chirality, hydrophobicity, biorecognition, and optical activity. Chirality arises from the interaction between the core, branching units, and surface groups. The internal structure, derived from AA building blocks, creates stereoselective sites for noncovalent binding of guest molecules.

These dendrimers are useful in protein mimicry, gene delivery, and targeted drug delivery due to their specific folding patterns. They are typically synthesized through direct use of amino acids or by grafting peptides onto traditional dendrimer surfaces or organic/peptide cores.[21]

Glycodendrimers

are derived from carbohydrates, which interact with specific receptors on cell surfaces, influencing various physiological and pathological processes. These interactions are particularly effective in multivalent ligand-receptor systems. Studies have shown that carbohydrates can serve as carriers within dendrimer structures.

Glycodendrimers have been explored for applications in cancer therapy, metastasis inhibition, and as immune stimulants, leveraging their ability to target specific cellular receptors through carbohydrate-mediated interactions.[22]

Hydrophobic dendrimers,

which need water solubility for systemic distribution, include internal hydrophobic gaps that effectively encapsulate and solubilise lipophilic molecules. Although their structure is similar to amphiphilic polymer micelles, they lack a critical micellar concentration (CMC) due to their covalently bound building blocks that remain stable in dilute fluids.These dendrimers typically have hydrophobic interiors and hydrophilic surfaces, forming unimolecular micelle-like structures. They have been used to solubilize hydrophobic probes, dyes, and fluorescent markers. Special types, like cyclophanes or dendrophanes, are capable of encapsulating both aliphatic and aromatic molecules. Additionally, they are valuable in controlled drug release applications.[23]

BASED ON STRUCTURE

Simple Dendrimers.

Simple dendrimers are made up of basic monomeric units created by symmetrically substituting benzene tricarboxylic acid ester. The structures consist of 4, 10, 22, or 46 symmetrically connected benzene rings, with a molecular diameter of around 45 Å. These dendrimers are the most basic kind of dendritic architecture, with a simple and consistent pattern.[21]

Crystalline dendrimers

Crystalline dendrimers are synthesized using mesogenic monomers, which are capable of forming ordered, crystalline structures. These monomers are typically created through the functionalization of carbosilane backbones. The resulting dendrimers exhibit a well-defined crystalline arrangement, making them suitable for applications requiring structural rigidity and order.

Chiral dendrimers

Chiral dendrimers, like pentaerythritol, have four distinct but chemically identical branches attached to a chiral core, resulting in their chirality. Chiral dendrimers are advantageous for enantioselective identification, chiral separation, and asymmetric catalysis due to their optical activity and stereochemical characteristics. [24]

Asymmetric dendrimers,

such as the well-known bow-tie polyester dendrimers developed by Gillies and Fréchet, are designed to offer improved pharmacokinetic profiles. These dendrimers are typically synthesized by attaching dendrons of different generations to a linear core, resulting in a nonuniform, orthogonal architecture. This asymmetry allows for tunable molecular weight, structure, and functional group density. Additionally, click chemistry has been employed by researchers like Lee and colleagues to synthesize advanced asymmetric dendrimers, such as generation 3 (G3) structures.[23]

Micellar Dendrimers: Aromatic, water-soluble hyperbranched dendrimers that mimic micelles and can encapsulate small organic molecules in aqueous environments.

Hybrid Dendrimers: Formed by functionalizing peripheral amines of polyethyleneimine, leading to structurally diverse, organized dendritic forms like dendritic-linear hybrids.

Amphiphilic Dendrimers: Feature both hydrophilic and hydrophobic regions by segregating electron-donating and withdrawing groups; examples include Superfect and hydraamphiphiles.

Metallodendrimers: Created via metal complexation at the core or surface, exhibiting electrochemical and luminescent properties; e.g., ruthenium bipyridine dendrimers.

Tectodendrimers: Contain a dendrimer core and are used for diagnostics and disease identification; examples include **Stratus® CS Acute Care™** and **Starburst®**.

Multilingual Dendrimers: Have multiple identical functional groups on their surface; VivaGel is a known example with therapeutic use.

Multiple Antigen Peptide (MAP) Dendrimers: Constructed using a polylysine skeleton; widely applied in vaccines and diagnostics due to their high antigenic density.[31]

PREPARATION OF DENDROSOMES: A COMPREHENSIVE APPROACH

Dendrosomes, which exhibit the complex and hierarchal branched structures of dendrimers, are being increasingly recognized as potential solutions for various biomedical applications, therefore requiring the efficient design of preparation pathways to preserve their unique structures and functions.

The formation of dendrosomes is a careful process that occurs in various steps, and many important variables must be controlled to achieve the ultimate structural and functional properties desired. The choice begins with a core molecule that is selected to serve as the core of the dendrosome before the iterative branching steps are completed. The nature of which core is critical to the final dendrosome, as it will dictate the overall size, shape, and function of the dendrosome, as the core can comprise a simple monomer, small molecule, or even a macromolecule. The specific form of the core will be influenced heavily by intended application. Once a core was selected, a layer-by-layer method was used to build the dendron by way of a stepwise synthesis, where each new generation of branching units was added to the previous layer by way of a series of chemical reactions. Each of these iterative generations was an addition applied on top of the previous generation, and each generation required precise controls surrounding the reaction conditions including temperature, reaction time, and reagent stoichiometry to assure complete and uniform growth in each generation, while limits on any defects to assure a complete structure.[16]

Thin film hydration method

Among various dendrosome preparation techniques, the thin-film hydration approach is simple, reproducible, and scalable, making it widely adopted. This method typically consists of dissolving lipids with any other hydrophobic compound in a organic solvent. Evaporating the organic solvent leaves a thin film of lipid on the walls of a round-bottom flask. An aqueous solution is subsequently added to rehydrate the lipid film, causing dendrosomes to spontaneously form. The resulting dendrosome suspension is then further processed to obtain the desired size distribution and homogeneity.

Ethanol injection

Commonly, ethanol injection is performed by re-dissolving the dendrimers and the cargo of interest, e.g., a drug or nucleic acid, in ethanol. The organic phase is directly injected quickly into the aqueous phase under controlled conditions and subsequent spontaneous self-assembly of dendrimers into vesicular structures encapsulates the cargo within the hydrophobic core or the hydrophilic shell. The rapid solvent polarity switch will cause the amphiphilic dendrimers to collapse and form spherical vesicles through the driven hydrophobic interactions between the alkyl chains of the dendrimers. Several parameters, such as the dendrimer generation, can influence both the size and morphology of the resulting dendrosomes**.**

Reverse phase evaporation

Water-soluble drugs or dendrimer complex can be loaded using this method and a similar reverse phase evaporation method to form dendrosomes. This approach involves dissolving lipids such as phosphatidylcholine and cholesterol in organic solvents like chloroform and ether. There, an aqueous solution of dendrimer-drug complex is created concurrently.

A solution of the water-soluble compounds in aqueous solution is slowly added to the lipid mixture and stirred or subjected to sonication to form a water-in-oil emulsion. Next, the organic solvents are removed with a rotary evaporator, resulting in the formation of lipid vesicles trapping the aqueous solution within. These vesicles, termed dendrosomes, can be oriented by sonication or filtered to minimize their size. Dialysis or centrifugation can be used to remove excess free dendrimer or drug. The final product may be stored in the fridge, or it can be lyophilized (freeze-dried) with stabilizers (e.g., mannitol) for long-time use.

Microfluidic method

Dendrosomes can be prepared by using the microfluidic method, a new technique that gives great control over particle size and composition. In this approach, a lipid solution (usually in ethanol or other organic solvent) is injected into one of the channels of a microfluidic chip, while an aqueous solution of the dendrimer or its complex is injected through another such channel. Once the two solutions converge inside the microfluidic chip under controlled laminar flow, they diffuse rapidly to self - assembly of dendrosomes. The two components assemble in water to give well-defined, stable nano-carriers, as the lipids self-assemble into bilayer vesicles around the aqueous environment of dendrimer solution. Dendrosome size and properties are tuneable by varying the flow rate ratio, concentration of components and chip design. The main advantages of this method are continuous production, high reproducibility and good control of the particle size and, in principle, scalability. This method can be beneficial for generating dendrosomes for targeted drug or gene delivery applications.

Sonication

Another sonication method that can form dendrosomes, and is one of the simplest methods; it is a simple process and a technique that has been commonly used to produce lipid-based nanoparticles is the sonication? In sonication, the phospholipids (for example, phosphatidylcholine) and cholesterol are dissolved in small amounts of organic solvent, then evaporated to form a thin film of lipid. Then the thin film can be hydrated with a dendrimer or dendrimer-drug complex in an aqueous medium. After hydrate multilamellar vesicles can be formed; followed by sonication, with a bath or probe sonicator, of the dispersion to reduce the size to yield uniform nanosized vesicles (dendrosomes). Sonication minimizes the size of the vesicles after hydration to form small unilamellar dendrosomes, which typically showed higher stability and drug encapsulation efficiency. Sonication is a simple and a fast method, does not require specialized equipment, so it is ideal for laboratory size formulations. However, it does limit control of size/ uniformity to a certain extent compared to more methodical methods like microfluidics.

Extrusion method

Another useful method to prepare dendrosomes is the extrusion technique which gives uniformly sized particles. In this approach, multilamellar vesicles are created by hydrating thin lipid films with an aqueous solvent containing the dendrimer or dendrimer-drug complex to form dendrosomes. The vesicles are then repeatedly extruded through polycarbonate membrane with defined pore sizes using an extruder. This process disaggregates larger vesicles and generates more homogeneous and controlled dendrosomes typically on the nanometre scale. The number of extrusion cycles and the membrane pore size can be varied to attain the final size of the particles. This method increases uniformity, increases drug encapsulation efficiency, and is relatively simple but may not be ideal for very large-scale production. Extrusion method is an excellent method to obtain stable dendrosomes for topically, orally or parenterally for drug delivery.

EVALUATION OF DENDROSOME

Evaluation Parameter	Purpose	Common Techniques
Particle Size	Determines nanoscale dimensions, affects biodistribution and cellular uptake	Dynamic Light Scattering (DLS), Transmission Electron Microscopy (TEM), Atomic Force Microscopy (AFM)
Morphology	Confirms vesicle structure and lamellarity	TEM, Scanning Electron Microscopy (SEM), AFM
Surface Charge (Zeta Potential)	Indicates colloidal stability and cell interaction	Zeta Potential Analyzer
Polydispersity Index (PDI)	Assesses size distribution uniformity	DLS
Encapsulation Efficiency	Measures drug loading capacity	UV-Vis Spectroscopy, HPLC
Drug Release Profile	Evaluates sustained/controlled release behavior	Dialysis Method, Franz Diffusion Cell
Cytotoxicity	Assesses biocompatibility and safety	MTT, XTT, Trypan Blue Exclusion Assay
Cellular Uptake	Measures efficiency of internalization	Confocal Microscopy, Flow Cytometry
Hemocompatibility	Ensures safety for blood-contacting applications	Hemolysis Assay, Platelet Aggregation Assay
Immunogenicity	Checks for immune system activation	ELISA, Cytokine Profiling
Biodistribution	Tracks in vivo localization and targeting ability	Fluorescence Imaging, Radio-labeling, Organ Harvesting
Pharmacokinetics	Determines circulation time and clearance	Blood Sampling, LC-MS/MS, In Vivo Imaging

Transmission Electron Microscopy (TEM) Analysis

Transmission electron microscopy was used to analyse the morphological characteristics of dendrosomes and to study liposomes-dendrimer interaction over time. Liposomes and dendrimers were mixed in a 100:10 (w/w) and sonicated. Microscopic analyses were performed at 0, 6, and 24 hours after mixing. The samples were prepared by adding a drop of 0.1% (w/v) phosphotungstic acid (PTA) for negative staining and then air-dried in a dark box to improve contrast, following the protocol from Ottaviani et al. (2000). All dendrosomal samples were imaged to the same protocol.[2]

Scanning Electron Microscopy (SEM)

SEM was used to study the surface morphology of dendrosomal formulations. A single drop of the dendrosomal suspension was applied to a clean coverslip and air-dried on a bench. The dried sample was secured to an aluminium stub using double-sided sticky copper tape. Gold coating was applied to the sample by sputtering to improve conductivity. The samples were analysed using a scanning electron microscope (SEM) at an accelerating voltage of 10-25 kV. Representative photos were generated to observe morphology.[8]

Dynamic Light Scattering (DLS) Analysis

The dendrosomal formulations were evaluated for particle size and polydispersity index (PDI) using DLS analysis. To analyse the dendrosomal dispersion, a 20 µL sample was diluted 100 times with PBS or another suitable buffer and analysed using Dynamic Light Scattering. The cumulant approach was used to analyse autocorrelation functions and provide particle size distributions and PDI. All measurements were carried out at 25°C. At 20°C, the Zetasizer was used to measure particle ζ-potentials and surface charge. [17]

Entrapment Efficiency

The entrapment efficiency was determined as the percentage of active substance encapsulated in the dendrosomes in relation to the total amount of drug originally added. A specified volume of the dendrosome dispersion (in PBS, pH 7.4 or some other suitable aqueous medium) was mixed with an equal volume of a suitable organic solvent to lyse the vesicles and release the entrapment content. The mixture was vortexed for 10 min and then centrifuged for 15 minutes at 2500 rpm. The supernatant was collected and spectrophotometrically analyzed at the specific wavelength for the compound, with suitable dilution if necessary. The reference sample was a blank containing unloaded dendrosomes.[8]

EE (%) = (Amount of encapsulated drug / Total drug added) x 100

***In Vitro* Drug Release Study**

The *In vitro* drug release of the formulations and pure drug were assessed by dialysis membrane method. Phosphate buffer solutions of chosen pH values (usually pH 7.4 and pH 5.4) were employed as release media to mimic physiological and pathological conditions. An equal amount of each formulation, equivalent to a predetermined amount of drug, was suspended in distilled water and placed in dialysis bags (molecular weight cut-off: 5 kDa). The dialysis bags were subsequently placed in 100 mL of the corresponding buffer solution and kept at 37 ± 0.5 °C under continuous stirring at 100 ± 20 rpm. Every time interval predetermined (up to 72 hours), 2 mL aliquots of the release medium were withdrawn and replaced with new buffer in order to preserve sink conditions. Drug content within collected samples was assayed using a proper analytical method (e.g., HPLC or UV-Vis spectrophotometry) at an appropriate wavelength. All experiments were performed in triplicate, and results were indicated as mean ± standard deviation.[2]

Cytotoxicity

Cytotoxicity tests of dendrosomes are performed to assess their efficacy and safety as nanocarriers, commonly employing *In vitro* assays such as MTT, LDH, or trypan blue exclusion on the appropriate cell lines such as HeLa, MCF-7, or HaCaT, depending on the target application. These tests measure parameters such as cell viability, IC50 values, and morphological changes following exposure of cells to different concentrations of blank and drug-loaded dendrosomes for 24–72 hours. Results typically indicate that blank dendrosomes have low cytotoxicity, which suggests good biocompatibility, whereas drug-loaded dendrosomes typically increase therapeutic efficiency in comparison with free drugs based on increased cellular uptake and controlled drug release. Further assessments can involve the generation of ROS or markers of apoptosis to identify more about the mechanism of cytotoxicity. Overall, dendrosomes prove to be promising as safe and effective delivery systems for topical, anticancer, or other biomedical uses.[26]

APPLICATIONS ON CANCER THERAPY

Dendrosomes address each of those issues in the following ways:

Targeted Drug Delivery: Dendrosomes have the capability to modify their surface with tumour specific ligands, allowing cytotoxic agents to be delivered directly to the user's cancer cells surface, reducing exposure to healthy tissues.

Enhanced Solubilizing Property: Dendrosomes enable solubilization of hydrophobic chemotherapeutic agents, promoting bioavailability and therapeutic efficacy.

Controlled Drug Release: Dendrosomes are designed to provide controlled drug release, hence clinical formulations with dendrosomes provide durability in therapeutic effect for long periods of time.

Animal model studies outlined the potential of dendrosomal formulations to provide significant reductions in tumours, making them very desirable candidates for clinical applications.[29]

Gene Therapy

Dendrosomes have incredible possibilities not only in drug delivery but also in gene therapy. They can alleviate nucleic acid delivery, both DNA and RNA that is relevant in studies of genetic disorders.

1. Nucleic Acid Protection: Dendrosomes can fully protect sensitive nucleic acids, thereby encapsulating those acids to prevent degradation in biological environments.

2. Enhanced Cellular Uptake: Dendrosomes surface properties can be modified for enhanced uptake by cells, which ensures genes that are therapeutic will enter target cells with adequate efficacy.

3. Transfection Efficiency: Dendrosomal carriers can permit increased transfection rates relative to normal methods and; thereby, increased therapeutic gene expression.

These characteristics have made dendrosomes a potential candidate for the development of innovative gene therapies. These properties have made dendrosomes almost a candidate in developing gene therapies.[27,28]

Vaccine Delivery

The use of dendrosomes extends into immunology, particularly in improving vaccine delivery, and efficacy:

1. Adjuvant Effect: Dendrosomes act as adjuvants, while also improving the body's immune response, thus enhancing efficacy.

2. Controlled Recovery of Antigens: The dendrosomal structure allows for a sustained release of antigen from the vaccine; this sustained recovery will potentially lead to sustained immune stimulation.

3. Targeting Vaccination: By modifying dendrosomes to target immune cells, researchers can further improve the effectiveness of nearly all vaccines.

This method is particularly effective with novel diseases and custom vaccines.[30]

CONCLUSION

Dendrosomes are a lipid-dendrimer hybrid vesicular system, that hold great potential as non-viral gene delivery vehicles due to ease of manufacture, high transfection efficiency, and very low haemolysis. Some unique characteristics include the fact they are inexpensive, very stable at room temperature, biocompatible, and take up quickly by cells during drug absorption. This highlights their utility as active therapeutically effective carrier systems in a biologically safe way. We have shown unequivocally the potential for some applications in gene therapy and DNA vaccines, where dose control, safety, and stability may be of utmost importance. These attributes not only position them to be future-generation nanocarriers for drug and gene delivery, but begs further investigation in larger clinical and preclinical trials to uncover their potential commercial applications as biomedical strategies of the future.

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