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Review Paper

Nasopulmonary Drug Delivery System Loaded Via Nanocarrier

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ABSTRACT

Nanocarrier-loaded nasopulmonary medication delivery devices present a promising approach for the effective and focused treatment of systemic and respiratory disorders. The formulation, characterisation, and efficacy of nanocarrier-based systems delivered via nasal and pulmonary routes are investigated in this work. Drug loading, particle size, stability, and release behaviour were assessed for a variety of nanocarriers, such as liposomes, polymeric nanoparticles, and solid lipid nanoparticles. In comparison to traditional formulations, experimental results showed increased drug penetration, greater mucosal adherence, and regulated release profiles. Due to localised administration, in vitro and ex vivo tests showed increased bioavailability and decreased systemic side effects. Deposition studies also verified effective dispersion in lung and nasal tissues. The findings demonstrate how nasopulmonary systems loaded with nanocarriers may enhance treatment outcomes, especially for systemic medication administration and chronic respiratory conditions. All things considered, this method offers a secure, non-invasive, and efficient platform for cutting-edge medication delivery applications. Future research will concentrate on scalability and clinical translation...

INTRODUCTION

Intranasal administration is particularly beneficial for drugs with poor oral stability, such as peptides and proteins. Additionally, it offers a non-invasive and convenient method that enhances patient compliance[1]. The nasal route also enables direct transport of drugs to the central nervous system via olfactory pathways, helping to overcome the blood–brain barrier. Due to these advantages, intranasal delivery has become an important focus in modern pharmaceutical research for both therapeutic and preventive applications[2-3].

For medications like proteins and peptides that have low oral stability, intranasal delivery is especially advantageous[4]. It also provides a convenient and non-invasive approach that improves patient compliance. Additionally, the

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nasal route helps to cross the blood-brain barrier by allowing medications to be directly transported to the central nervous system via olfactory pathways[5]. Because of these benefits, intranasal administration has gained significant attention in contemporary pharmaceutical research for both therapeutic and preventive uses[6].

ANATOMY AND PHYSIOLOGY OF NASOPULMONARY DRUG DELIVERY SYSTEM

Table 1: Anatomy and physiology of nasopulmonary drug delivery system[7-15]

Sr. no.	Component	Anatomy	Physiology (function)	Methodology (study/approach)	Outcome of work
1	**Nasal cavity**	Coated with mucosa and cilia and separated into two chambers by a septum.	Heats, humidifies, and filters air.	Investigation of airflow and microscopic examination of the epithelial lining.	Effective air cooling and big particle removal.
2	**Nasal mucosa**	Goblet cells in a highly vascularised epithelial layer.	Secretes mucus to collect microorganisms and dust.	Investigation of mucus formation, monitoring of mucociliary clearance, and examination of medication passage via the nasal epithelium.	Improved defence and possibility for drug absorption.
3	**Olfactory region**	Has olfactory receptors on the roof of the nasal cavity.	In charge of smell.	Neural pathway research and receptor mapping.	A crucial pathway for medication administration from the nose to the brain.
4	**Pharynx**	The muscular tube that joins the larynx and nasal cavity.	Air and food passage.	Imaging methods (CT/MRI).	Makes sure the lower respiratory tract has easy access to air.
5	**Larynx**	Vocal cord-containing cartilaginous structure.	Airway protection and voice production.	Endoscopic analysis.	Prevents food from entering the lungs.
6	**Trachea**	Ciliated lining and C-shaped cartilaginous rings.	Removes particulates and transports air to bronchi.	Airflow and microscopic investigations.	Preserves particle clearance and an unobstructed airway.
7	**Bronchi**	The trachea branches into the lungs in two primary ways.	Provides air to the lungs	Research on bronchoscopy.	Effective dispersion of air.
8	**Bronchioles**	Cartilage-free, smaller airway branches.	Manage resistance and airflow	Tests of pulmonary function.	Regulation of airflow to alveoli.
9	**Alveoli**	Rich capillary network; tiny air sacs with narrow walls.	Exchange of gases (O_2 and CO_2).	Gas diffusion research and microscopy.	Effective elimination of carbon dioxide and intake of oxygen.

10	**Lungs**	Lobe-separated spongy organs.	Primary respiratory location	Spirometry and imaging (CT scan, X-ray).	Efficient gas exchange and breathing.
11	**Pulmonary circulation**	Blood vessel network around alveoli.	Moves gases from the lungs to the blood.	Analysis of blood gas.	Preserves blood's oxygenation.

- **There are three components to the nasal cavity area:**

1. The nasal vestibule

The lobby is the first area of the airway that comes into contact with the external environment. In contrast to the rest of the nasal cavity, the vestibule is lined with stratified epithelium.

2. **Breathing zone**

The breathing zone is the part of the lungs (alveoli) where oxygen enters the blood and carbon dioxide is removed. It helps supply oxygen needed for Cellular Respiration in body cells. It also maintains proper balance of gases and supports normal body functioning[16].

3. The olfactory region

The olfactory region is a specialized area in the upper part of the nasal cavity responsible for the sense of smell. It contains sensory receptors that detect odor molecules and convert them into nerve signals, which are then sent to the brain for identification. This process allows us to recognize different smells and also contributes to taste and environmental awareness.

- **Vestibule**

The nasal vestibule filters large particles using nose hairs and mucus. It also protects the airway by trapping dust and germs before they enter deeper respiratory parts. It contributes to the humidification and slight warming of incoming air, facilitating easier breathing[17].

- **Nasal valves**

The nasal valve regulates airflow by controlling the resistance of air entering the nasal cavity. It helps direct and limit airflow to ensure efficient breathing and prevents the nasal passages from collapsing during inhalation.

- **Nasal septum**

The nasal septum separates the nasal cavity into two passages, ensuring even airflow through both nostrils. It provides structural support to the nose and helps direct incoming air for proper filtering, warming, and humidifying[18].

- **Nasopharyngeal region**

The nasopharyngeal region allows air to move from the nasal cavity to the throat for respiration. It filters dust and microbes using mucus and cilia, helping keep the air clean. It also warms and moistens inhaled air for easy breathing. It provides immune defense through lymphoid tissue and helps clear mucus to maintain an open and healthy airway[19].

- **Trachea bronchial region**

The trachea conducts air between the larynx and the bronchi. It also filters, warms, and moistens the air before it enters the lungs[20].

- **Lungs**

The lungs help the body breathe by taking in oxygen and removing carbon dioxide. Oxygen from the air enters the blood in the alveoli, while carbon dioxide from the blood is released and breathed out. This process supports energy production in body cells and keeps the internal environment balanced[21]. Lungs act as organs that exchange gases between air and blood to keep the body alive and functioning properly.

- **Pulmonary epithelium**

The pulmonary epithelium forms a barrier that protects lung tissue from harmful substances and pathogens. It also facilitates gas exchange and helps maintain fluid balance in the lungs.

➢ **The bronchi**

The bronchi conduct air between the trachea and the bronchioles in the lungs. They also filter, warm, and moisten the air before it reaches deeper parts of the lungs[22].

➢ **Bronchioles**

Bronchioles are small air passages that carry air from the bronchi to the alveoli in the lungs. They regulate airflow by expanding or narrowing, ensuring proper distribution of air for gas exchange.

➢ **Alveolar region**

The alveolar region is responsible for gas exchange, allowing oxygen to enter the blood and carbon dioxide to leave it. It also helps maintain efficient respiration due to its thin walls and large surface area[23].

MECHANISM OF ACTION OF NASO DRUG DELIVERY SYSTEM

There are two main ways in which drug molecules pass through the nasal mucosa.

1. **Trancellular pathway:** This is the preferred route for lipophilic drugs because they can dissolve in the lipid bilayer of cells film. They pass directly through the epithelial cells of the nasal mucosa[24].
2. **Paracellular pathway:** Most drugs that use this route are hydrophilic, making it difficult for them to enter the body of the cell membrane. They move through the spaces created by epithelial cells[25-26].

3. ***Table 2: List of mechanisms of nasal drug delivery systems[27-28]***

Sr. No.	Mechanism	Description
1.	Trans cellular Pathway	Lipophilic drugs pass directly through the membrane of epithelial cells.
2.	Para cellular Pathway	Hydrophilic drugs are permeable Space between epithelial cells.

CONTROLLED RELEASE DRUG DELIVERY SYSTEM

Controlling medicine concentrations, reducing the number of doses, maximising drug use, and enhancing patient adherence are all made possible by controlled release drug delivery systems. However, compared to conventional pharmaceutical formulations, they may also have drawbacks such material toxicity, biocompatibility problems, unwanted product degradation, the need for surgery, patient discomfort, and greater prices[29]. A zero-order release profile indicates consistent drug release, and controlled drug delivery is the regulated administration of a medication over a predefined period of time. Conversely, sustained release dosage forms are administered in a certain way that ensures a prolonged but erratic therapeutic concentration. The first dose is administered quickly, and the remaining dose is released gradually[30]. The effectiveness of nasal and pulmonary drug delivery channels, which are widely utilised for both local and systemic therapy, is greatly improved by Controlled Drug Delivery Systems (CDDS). These pathways have special benefits, such as a large absorptive surface area, a quick beginning of action, and avoidance of first-pass metabolism.

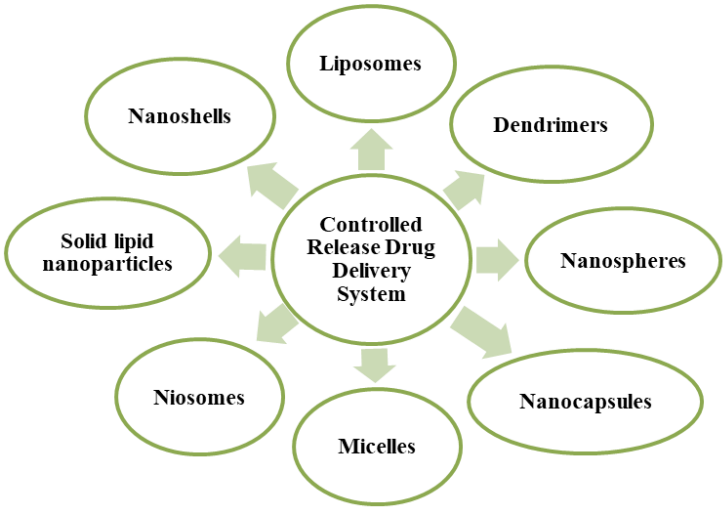

Fig 1: Controlled Release Drug Delivery System

BENEFITS OF CONTROLLED RELEASE DRUG DELIVERY SYSTEM

1. **Sustained drug release**: Systems for controlled release offer a steady and prolonged pharmaceutical release over an extended duration, guaranteeing a steady and therapeutic drug concentration in the body.
2. **Fewer frequent doses:** CDDS often allows for less frequent dosing regimens than formulations for immediate release, which improves patient convenience and compliance.
3. **Decreased side effects:** By carefully releasing the medicine, peak plasma concentrations can be decreased, potentially reducing adverse side effects and enhancing the treatment's safety profile.
4. **Enhanced efficacy:** These systems may increase a medication's efficacy and potentially improve treatment outcomes by optimising drug delivery to the intended site.
5. **Better bioavailability:** Controlled release formulations, which keep drug levels within the therapeutic range, can provide longer-term drug absorption and bioavailability.
6. **Reduced administration frequency:** Extended-release formulations can improve patient comfort and adherence by reducing the daily dosage requirements.
7. **Targeted medication delivery:** Certain controlled release systems can reduce off-target effects and improve medication delivery efficacy by concentrating on specific tissues or cells[31-32].

Commonly Used Nanocarriers for Nasopulmonary Delivery

Table 3: Commonly used nanocarriers for nasopulmonary delivery [33-37]

Sr no.	Nanocarrier	Particle size (nm)	Method of preparation	Outcome of work	Advantages	Disadvantages
1	Liposomes, Niosomes, Sphingosomes	20–3500	Thin-film hydration, solvent evaporation, sonication	Improved drug delivery and imaging efficiency	Can be labelled with radionuclides; enhances imaging and therapy	Lengthy radiolabelling process; requires strict control

2	Micelles	20–150	Self-assembly of amphiphilic molecules	Efficient drug solubilisation and reduced RES uptake	Easy to prepare; reduced RES clearance	Requires careful amphiphilic chelator design
3	Nanoparticle / Solid Lipid Nanoparticle	10–1000	homogenisation, nanoprecipitation	Targeted drug delivery	Avoid RES uptake; versatile drug loading	Limited control over size and distribution
4	Dendrimers	~10	Divergent/convergent stepwise synthesis	Better distribution of biodiversity	Clear structure and low polydispersity	Potential toxicity because of surface charge
5	Nanoparticles of gold	1–100	Chemical reduction, such as the reduction of citrate	Photothermal treatment and cancer diagnostics	Distinctive visual characteristics	Concerns about toxicity (core and ligands)
6	Tiny bubbles	About 500	Agitation or sonication	Drug administration and imaging in capillaries	Safe; imitate the behaviour of red blood cells	Heat generation risk and short circulation time
7	Nanoparticles with magnetic properties	10–50	Thermal breakdown and co-precipitation	Magnetic medication targeting	Magnetic field-based external control	Oxidation problems and metal toxicity
8	Dots of Quantum	2–10	The sol-gel method of colloidal synthesis	Bioimaging and diagnostics with high resolution	Outstanding stability, adjustable emission, and fluorescence	Possible toxicity from heavy metals (e.g., Cd); long-term safety issues

1. LIPOSOMES

Liposomes are spherical nanocarriers that contain phospholipid bilayers and an aqueous core. They protect hydrophilic and lipophilic medications from deterioration and improve absorption through the mucosa of the nose and lungs. Sprays, nebulisers, and inhalers are used in nasopulmonary delivery[38]. By adhering to the respiratory epithelium, liposomes (50–500 nm) improve drug stability and efficacy and reduce systemic side effects while facilitating targeted delivery to lung tissues[39-40].

2. MICELLES

Amphiphilic molecules in water self-assemble to create micelles, which are tiny transporters. They allow for targeted drug administration and range in size from 10 to 100 nm[41]. They administer medications through sprays or inhalation in nasopulmonary systems, avoiding first-pass metabolism and guaranteeing quick absorption[42]. They are helpful for medications that are poorly soluble in water, such as anticancer, anti-inflammatory, and antibiotics[43].

Mechanism of micelles nanocarrier used in nasopulmonary system

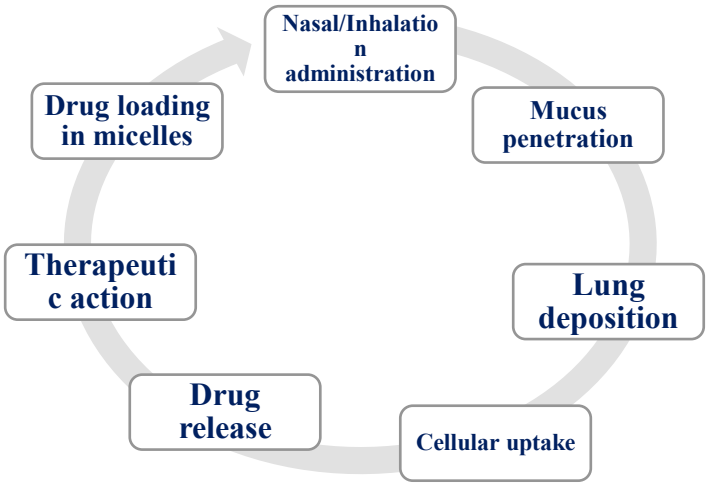

Figure 2 :- Mechanism of micelles nanocarrier used in nasopulmonary system

3. GOLD NANOPARTICLES

Gold nanoparticles (AuNPs) are exceedingly small gold particles, typically ranging in size from 1 to 100 nm[44]. They are commonly used as drug delivery nanocarriers due to their biocompatibility, large surface area, and ease of surface modification. Gold nanoparticles facilitate the direct administration of medications to the respiratory tract or systemic circulation through the nasopulmonary drug delivery system, utilising the nose and lungs[45].

4. DENDRIMERS

Synthetic, highly branched nanocarriers called dendrimers are utilised in nasopulmonary medication administration by inhalation or nasal sprays. Drugs might be linked to surface groups or contained within the core due to their structure. PAMAM and PPI dendrimers are common varieties[46]. They improve the bioavailability, stability, and solubility of medicines, particularly those that are unstable or poorly soluble. Targeted and regulated drug delivery to the respiratory system is made possible by dendrimers[47]. They are being researched for the treatment of lung conditions such as cystic fibrosis, cancer, asthma, and tuberculosis. Dendrimers also enhance nasal mucosal absorption, which increases therapeutic efficacy by facilitating quicker drug delivery to lung tissues or systemic circulation[48].

5. QUANTUM- DOTS

Quantum dot–polymer materials are hybrids where very small semiconductor particles are combined with polymer substances. The quantum dots provide special light and electronic properties, while the polymer acts as a flexible, protective support. This combination makes the material stable, easy to shape, and useful in devices like displays, sensors, and medical tools[49].

Mechanism of action of loaded drug via nanocarrier

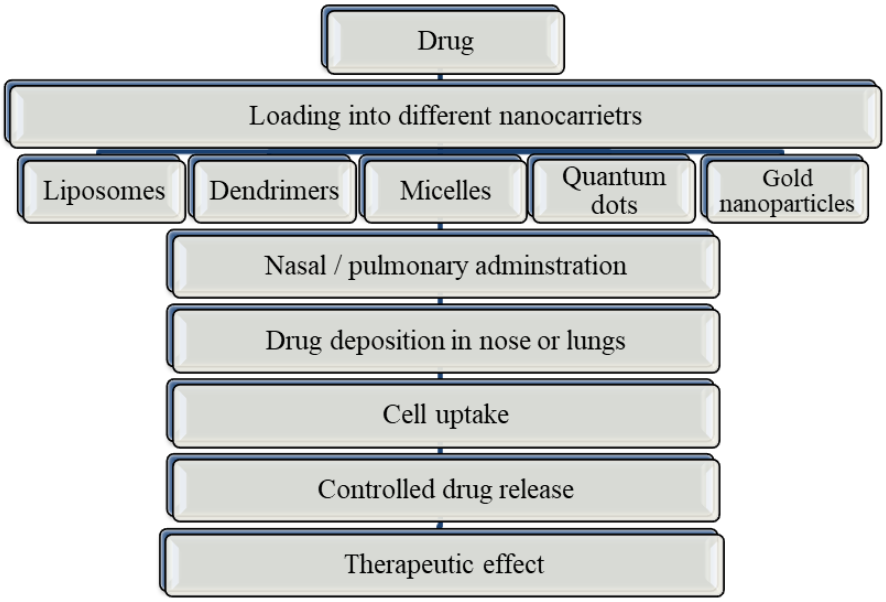

Fig 3: Mechanism of action of loaded drug via nanocarrier

NASO-PULMONARY MEDICATION DELIVERY SYSTEMS'S DOSAGE FORMS

1. Nassal drops

They represent the simplest and most effective nasal drug delivery system currently available. Nose drops can be applied using a pipette or a squeezy bottle. For the treatment of local issues such as microbial growth, mucosal malfunction, and nonspecific loss of the nose or lower back, these medication formulations are often recommended. Nasal drops may not be useful for prescription drugs because the system's primary flaw is its lack of dosing precision. Nasal drops have been shown to deposit human serum albumin in the nostrils more successfully than nasal sprays [50-51].

Table 4:- Method of nasal drops loaded via nanocarrier

Drugs	Nanocarrier	Methodology (drug loading via nanocarrier)	Outcome of work
Salbutamol	Chitosan nanoparticles	A polymer solution is created by dissolving chitosan in diluted acetic acid. This solution is mixed with salbutamol. The medication is then encapsulated in chitosan nanoparticles by adding sodium tripolyphosphate (TPP) dropwise while stirring continuously (ionic gelation process). After that the nanoparticles are collected and distributed in an appropriate nasal drop medium.	Enhanced drug absorption through nasal mucosa, rapid onset of bronchodilation, improved bioavailability, reduced dose requirement, and better patient compliance due to non-invasive administration.

2. Nasal sprays

Nasal sprays are composed of suspension and solution. A nasal spray can accurately deliver a dose between 25 and 200 µm when metered dose pumps and actuators are available[52]. The drug's morphology, formulation viscosity, and particle size (for suspensions) all influence the choice of pump and actuator assembly[53-54].

Table 5 :- Method of nasal spray drug loaded via nanocarrier

Drugs	Nanocarrier	Methodology (drug loading via nanocarrier)	Outcome of work
Fluticasone propionate	Nanoemulsion (for nasal spray)	Oil phase (e.g., isopropyl myristate) and surfactant (e.g., Tween 80) are mixed, and Fluticasone propionate is dissolved in the oil phase. This is emulsified with the aqueous phase using high-speed homogenization followed by ultrasonication to form a stable nanoemulsion. The formulation is adjusted for suitable viscosity and filled into a nasal spray container.	Increased bioavailability, uniform dose delivery, quick beginning of action, improved nasal absorption, improved medication solubility and stability, and efficient treatment of asthma and allergic rhinitis

3. Nasal gels

Nasal gels were not very popular prior to the recent development of an exact dosing device. Nasal gels are highly viscous liquids or solutions that have been thickened[55]. The benefits of nasal gels include reduced post-nasal drip due to their high viscosity, a diminished flavour effect from less swallowing, decreased anterior formulation leakage, and increased comfort from soothing and emollient ingredients[56].

Table 6:- Method of nasal gel drug loaded via nanocarrier

Drugs	Nanocarrier	Methodology (drug loading via nanocarrier)	Outcome of work
Budesonide	Liposomes (incorporated into nasal gel)	Phospholipids and cholesterol are dissolved in an organic solvent (like chloroform) to create liposomes. To create a thin lipid layer, the solvent is evaporated. Drug-loaded liposomes are created by adding budesonide in the aqueous phase, hydrating the lipid film, and then sonicating the mixture. To make nasal gel, these liposomes are then gently stirred into a gel base (such as Carbopol or HPMC).	Better therapeutic efficacy, prolonged drug release, protection against drug degradation, increased bioavailability, fewer doses, and greater medication penetration through the nasal mucosa.

4. Nasal powders:

This dosage form may be developed if solution and suspension dosage forms cannot be made, for example, due to a drug's instability[57]. The benefits of the nasal powder dose form include the absence of an improved stability and preservative in the formulation. However, whether the powder formulation is suitable depends on the solubility, particle size, aerodynamic properties, and nasal irritation of the active drug and excipients[58]. The drug's local application is another advantage of this approach, as it allows for targeted delivery to the nasal mucosa, potentially enhancing therapeutic effects while minimising systemic side effects[59].

5. DPIs, or dry powder inhalers

Depending on the source of airflow for powder aerosolisation, there are two types of dry powder inhalers: passive and active. Additionally, they come in single-use, multi-dose, and reusable varieties[60]. They are classified into various categories based on the method of powder dispersion, the capacity of the dose, and the level of patient involvement during the powder

aerosolisation process. DPIs are separated into three categories based on dose capacity: medium-dose capacity aerosolisation, low-dose capacity devices, and powder dispersion mechanisms[61]. These devices can be categorised as single-unit dose, multi-unit dose, and multi-dose reservoirs in terms of dose capacity. They have been used to treat diabetes mellitus as well as conditions like asthma, bronchitis, emphysema, and COPD[62-63].

Table 7:- Method of dry powder inhalers drug loaded via nanocarrier

Drugs	Nanocarrier	Methodology (drug loading via nanocarrier)	Outcome of work
Fluticasone	Polymeric Nanoparticles (PLGA)	An organic solvent, such as dichloromethane, is used to dissolve PLGA. This polymer solution is mixed with fluticasone. Using high-speed homogenisation (emulsion-solvent evaporation method), this mixture is emulsified into an aqueous phase that contains a stabiliser (such as PVA). Drug-encapsulating nanoparticles are created as the solvent evaporates. After that, these nanoparticles are gathered and spray-dried with lactose to create an inhalable dry powder.	In managing asthma, controlled drug release, better lung targeting, increased anti-inflammatory impact, and fewer doses

6. Metered dose inhalers (MDI)

A metered-dose inhaler (MDI) is a device that allows patients to self-administer a certain amount of medication by inhaling a brief burst of aerosolised drug into their lungs[64]. A pressurised medication container that fits into a mouthpiece is a feature of the Meter Dose Inhaler (MID). By inserting the container into the mouthpiece, a dose of medication is released into the lungs[65].

Table 8 :- Method of Metered Dose Inhaler Drug Loaded via Nanocarrier

Drugs	Nanocarrier	Methodology (drug loading via nanocarrier)	Outcome of work
Albuterol	Polymeric Nanoparticles (PLGA)	Dichloromethane is one example of an organic solvent that dissolves PLGA. This polymer solution is combined with albuterol. High-speed homogenisation (emulsion-solvent evaporation method) is used to emulsify the mixture into an aqueous phase with a stabiliser such as PVA. The drug-loaded nanoparticles are created by evaporating the organic solvent. To create the metered dose inhaler formulation, these nanoparticles are gathered and subsequently distributed in an appropriate propellant (such as HFA-134a) with surfactants.	In asthma treatment, rapid bronchodilation, better lung deposition, regulated medication release, fewer doses, and improved therapeutic effect

7. Nebulizers

The two nebulisers available differ in the force used in the creation of the aerosol from the corresponding liquid. Depending on the model and manufacturer, nebulisers produce droplets with a diameter of 1-5 µm. These devices do not demand coordination of the patient with inhalation and actuation of the device. Therefore, nebulisers are used in paediatric patients, elderly patients, ventilated patients, non-conscious patients, or those incapable of using pMDIs or DPIs[66-67].

Table 9: Nasopulmonary medication delivery system dosage form

Srno	Dosage form	Method of preparation	Uses	Outcomes of work	Advantages	Disadvantages
1	**Nasal drops**	A drug suspended or dissolved in an oily or aqueous base, then sterilised and put into a dropper bottle.	Sinusitis, allergies, and nasal congestion.	Localised medication effect in the nasal cavity.	Easy to use, inexpensive, and rapid relief.	Inaccurate dosage, throat drainage, and brief duration.
2	**Nasal sprays**	Prepared as suspensions or solutions and put into containers for metered-dose spraying.	Decongestion, vaccinations, and allergic rhinitis.	Uniform dispersion throughout the nasal mucosa.	Convenient and more accurate than drops.	Irritation, drug volume restriction, and potential contamination.
3	**Nasal gels**	Medication added to the gel base (such as carbopol); modified viscosity and pH.	Extended nasal medication administration.	Extended contact time and prolonged release.	Enhanced absorption, airflow and decreased outflow.	May be uncomfortable and challenging to administer.
4	**Dry powder inhalers (DPI)**	Medication that has been micronised, combined with carriers (like lactose), and put into capsules or other containers.	Asthma, COPD.	Lung deposition in depth.	Breath-activated, requiring no propellant.	Requires patience and is sensitive to dampness.
5	**Metered dose inhalers (MDI)**	Pressurised canisters are loaded with a drug that has been dissolved or suspended in propellant.	Breathlessness and asthma.	Quick bronchodilator.	Accurate, portable dosing.	Coordination is necessary and propellant-related problems.
6	**Nebulizers (solutions/suspensions)**	Drug suspended or dissolved in sterile liquid; utilised in a nebuliser.	Severe infections and asthma.	Constant delivery of aerosols.	All ages can use it; coordination is not required.	Time-consuming, bulky, and contaminated.
7	**Nasal powders**	The medication was ground into a fine powder and used in insufflators.	Systemic administration (such as hormones or vaccinations.	Enhanced absorption and stability.	Stable formulation and no need for preservatives.	Irritation, inconsistent dosage, and discomfort.

OUTCOMES

When paired with nanocarrier-based technologies, recent developments in nasopulmonary drug delivery systems have shown notable increases in therapeutic efficacy. Together, the evaluated trials show improved controlled release patterns, bioavailability, and drug targeting.

1. Increased Bioavailability of Drugs

- Boost drug solubility, particularly for medications that are poorly soluble in water.

- Extend the duration of stay in the pulmonary and nasal cavities.
- Promote quick absorption through the alveolar epithelium and highly vascularised nasal mucosa.

2. Targeted Medication Administration

- Targeting the brain or lung tissues specifically (via the nose-to-brain route).
- Diminished systemic adverse effects.
- Enhanced therapeutic index.

4. Sustained and Regulated Release

- prolonged medication release (up to 24–72 hours).
- decreased frequency of dosage.
- Enhanced adherence to treatment.

5. Enhanced Mucosal Infiltration

- Improved retention at the place of administration.
- Enhanced permeability across mucosal barriers.
- Decreased removal of mucus.

6. Disease Management Applications

- respiratory conditions (tuberculosis, COPD, and asthma).
- Neurological conditions (via nose-to-brain delivery).
- Infectious diseases (including antibacterial and antiviral treatments).

7. Profile of Safety and Toxicity

- Nanocarriers' acceptable biocompatibility.
- Minimal local irritation of the pulmonary and nasal tissues.
- Long-term toxicity and accumulation, however, are still issues that need more research.

CONCLUSION

Nasopulmonary drug delivery systems loaded with nanocarriers are a new approach in modern therapeutics, offering significant advantages over conventional delivery methods. The integration of nanotechnology with nasal and pulmonary routes has improved treatment outcomes by enabling targeted distribution, controlled release, and increased drug absorption.Examples of nanocarriers that have demonstrated potential in overcoming physiological barriers, including mucociliary clearance and limited membrane permeability, include polymeric nanoparticles, liposomes, dendrimers, and nanoemulsions. Because they offer efficient pharmaceutical transport across nasal mucosa and deep lung tissues, as well as the potential for direct nose-to-brain delivery, these devices are particularly helpful for both neurological and respiratory conditions. Furthermore, the ability to alter nanocarrier properties, including particle size, surface charge, and functionalisation, has enabled precision targeting and fewer systemic side effects. This lowers the frequency of dosages and improves patient compliance through prolonged and controlled medication release characteristics.Despite these positive achievements, a number of challenges remain. Consideration must be given to long-term safety, potential toxicity, large-scale production, regulatory approval, and stability of nanocarrier systems. To validate the safety and efficacy discovered in preclinical research, more comprehensive clinical trials are also necessary.

REFERENCES

1. Illum, L., Jorgensen, H., Bisgaard, H., & Rossing, N. (1987). Bioadhesive microspheres as a potential nasal drug delivery system. International Journal of Pharmaceutics, pp. 189–199.
2. Patton, J. S. (1996). Mechanisms of macromolecule absorption by the lungs. Advanced Drug Delivery Reviews, pp. 3–36.

3. Chien, Y. W., Su, K. S. E., & Chang, S. F. (1989). Nasal systemic drug delivery (Vol. 1, pp. 1–77). New York: Marcel Dekker.
4. Akwete, A. L., & Gupta, P. K. (Eds.). (1997). Delivery of biotherapeutics by inhalation aerosol. In Inhalation delivery of therapeutic peptides and proteins (pp. 151–231). New York: Marcel Dekker.
5. Marcel Dekker, Inc. (1997). Inhalation delivery of therapeutic peptides and proteins (pp. 151–231). New York: Author.
6. Aulton, M. E. (2002). Pharmaceutics: The science of dosage form design (p. 494). New York: Churchill Livingstone.
7. Ghadiri, M., Young, P. M., & Traini, D. (2019). Strategies to enhance drug absorption via nasal and pulmonary routes. Journal of Pharmaceutics, 11, 113.
8. Rahul, C., Krupraj, K., & Patel, V. P. (2013). Recent advances in pulmonary drug delivery system. Pharma Science Monitor, 4.
9. Jadhav, K. R., et al. (2007). Nasal drug delivery system—factors affecting and applications. Current Drug Therapy, 2(1), 27–38.
10. Johnson, N. J., Hanson, L. R., & Frey, W. H. (2010). Trigeminal pathways deliver a low molecular weight drug from the nose to the brain and orofacial structures. Molecular Pharmaceutics, 7, 884–893.
11. Mouez, M. A., Zaki, N. M., Mansour, S., & Geneidi, A. S. (2014). Bioavailability enhancement of verapamil HCl via intranasal chitosan microspheres. European Journal of Pharmaceutical Sciences, 51, 59–66.
12. Pilcer, G., & Amighi, K. (2010). Formulation strategy and use of excipients in pulmonary drug delivery. International Journal of Pharmaceutics, 392(1–2), 1–19.
13. Ghori, M. U., Mahdi, M. H., Smith, A. M., & Conway, B. R. (2015). Nasal drug delivery systems: An overview. American Journal of Pharmacological Sciences, 3(5), 110–119.
14. Deshpande, A. A., Shah, N. H., Rhodes, C. T., & Malick, W. (1997). Development of a novel controlled-release system for gastric retention. Pharmaceutical Research, 6, 815–819.
15. Singh, K., Gaikwad, D. D., & Singh, S. (2022). Journal of Population Therapeutics and Clinical Pharmacology, 29(1), 356–367.
16. Katzung, B. G. (2018). Basic and clinical pharmacology (14th ed., pp. 23–28).
17. Sherwood, L. (2016). Human physiology (9th ed., pp. 420–426).
18. Drake, R., et al. (2015). Gray's anatomy for students (3rd ed., pp. 102–108).
19. Tortora, G. J., & Derrickson, B. (2017). Principles of anatomy and physiology (15th ed., pp. 880–885).
20. Walsh, G. (2003). Biopharmaceuticals (2nd ed., pp. 320–325).
21. Hickey, A. J. (2012). Particle size and aerodynamic behavior in drug delivery (pp. 90–96).
22. Patton, J. H., & Byron, P. R. (2007). Pulmonary drug delivery mechanisms (pp. 147–159).
23. Dhuria, S. V., Hanson, L. R., & Frey, W. H. (2010). Intranasal delivery to the central nervous system. Journal of Pharmaceutical Sciences, 99, 1654–1673.
24. Verma, P. S. (2025). Title of the article. International Journal of Research Publication and Reviews, 6(12), 2438–2451.
25. Ibrahim, A., Mohamed, O., Abo Dena, A., & El-Sherbiny, I. (2023). Current advancements in nasopulmonary drug delivery systems.
26. Handa, M., et al. (2021). Therapeutic potential of nanoemulsions for targeting Alzheimer's disease. Drug Discovery Today, 26(12), 2881–2888.
27. Chhajed, S., Sangale, S., & Barhate, S. D. (2011). Advantageous nasal drug delivery

system: A review. International Journal of Pharmaceutical Sciences and Research, 2(6), 1322.
28. Lee, P. I., & Li, J. X. (2010). Evolution of oral controlled release dosage forms.
29. Ye, M., Kim, S., & Park, K. (2010). Issues in long-term protein delivery. Journal of Controlled Release, 146(2), 241–260.
30. Jain, S., et al. (2020). Controlled drug delivery systems: A review. Pharmaceutical Methods, 11(2), 121–138.
31. Patil, S., et al. (2019). Challenges and strategies in drug delivery systems. International Journal of Research in Pharmaceutical Sciences, 10(4), 717–722.
32. Kesharwani, P., Jain, K., & Jain, N. K. (2014). Dendrimer as nanocarrier. Progress in Polymer Science, 39(2), 268–307.
33. Arvizo, R., Bhattacharya, R., & Mukherjee, P. (2010). Gold nanoparticles in nanomedicine. Expert Opinion on Drug Delivery, 7(6), 753–763.
34. Sirsi, S. R., & Borden, M. A. (2009). Microbubble applications. Bubble Science, Engineering & Technology, 1(1–2), 3–17.
35. Vatta, L. L., Sanderson, R. D., & Koch, K. R. (2006). Magnetic nanoparticles. Pure and Applied Chemistry, 78(9), 1793–1801.
36. Qi, L., & Gao, X. (2008). Quantum dots in drug delivery. Expert Opinion on Drug Delivery, 5(3), 263–267.
37. Landesman-Milo, D., Goldsmith, M., Leviatan, B. S., Witenberg, B., Brown, E., Leibovitch, S., Azriel, S., Tabak, S., Morad, V., & Peer, D. (2013). Title of the article. Cancer Letters, 334, 221–227.
38. Allen, T. M., & Cullis, P. R. (2013). Title of the article. Advanced Drug Delivery Reviews, 65, 36–48.
39. Immordino, M. L., Dosio, F., & Cattel, L. (2006). Title of the article. International Journal of Nanomedicine, 1(3), 297–315.
40. Yingchoncharoen, P., Kalinowski, D. S., & Richardson, D. R. (2016). Title of the article. Pharmacological Reviews, 68, 701–787.
41. Liu, Y., Fu, S., Lin, L., Cao, Y., Xie, X., Yu, H., Chen, M., & Li, H. (2017). Redox-sensitive Pluronic F127-tocopherol micelles: Synthesis, characterization, and cytotoxicity evaluation. International Journal of Nanomedicine, 12, 2635–2644.
42. Patil, S., Ujalambkar, V., Rathore, A., Rojatkar, S., & Pokharkar, V. (2019). Galangin-loaded galactosylated Pluronic F68 polymeric micelles for liver targeting. Biomedicine & Pharmacotherapy, 112, 108691.
43. Zhao, J., Xu, Y., Wang, C., Ding, Y., Chen, M., Wang, Y., Peng, J., Li, L., & Lv, L. (2017). Soluplus/TPGS mixed micelles for dioscin delivery in cancer therapy. Drug Development and Industrial Pharmacy, 43, 1197–1204.
44. Jiang, Y., Huo, S., Hardie, J., Liang, X. J., & Rotello, V. M. (2016). Title of the article. Expert Opinion on Drug Delivery, 13, 547–559.
45. Riley, R. S., & Day, E. S. (2017). Title of the article. Wiley Interdisciplinary Reviews: Nanomedicine and Nanobiotechnology, 9, e1449.
46. Mendes, L. P., Pan, J., & Torchilin, V. P. (2017). Title of the article. Molecules, 22(9), 1401.
47. Sherje, A. P., Jadhav, M., Dravyakar, B. R., & Kadam, D. (2018). Title of the article. International Journal of Pharmaceutics, 548, 707–720.
48. Roy, R., & Baek, M. G. (2002). Title of the article. Journal of Biotechnology, 90, 291–309.
49. Loczechin, A., Séron, K., Barras, A., Giovanelli, E., Belouzard, S., Chen, Y. T., Metzler-Nolte, N., Boukherroub, R.,

Dubuisson, J., & Szunerits, S. (2019). Title of the article. ACS Applied Materials & Interfaces, 11, 42964–42974.

50. Aurora, J. (2002). Development of nasal delivery systems: A review. Drug DeliveryTechnology, 2(7), 101–130.
51. Rudman, K. L., O'Brien, E. K., & Leopold, D. A. (2011). Radiographic distribution of drops and sprays within the sinonasal cavities. American Journal of Rhinology & Allergy, 25, 94–97.
52. Hardy, J. G., Lee, S. W., & Wilson, C. G. (1985). Intranasal drug delivery by spray and drops. Journal of Pharmacy and Pharmacology, 37, 294–297.
53. Giuliani, A., Balducci, A. G., Zironi, E., Colombo, G., Bortolotti, F., Lorenzini, L., et al. (2018). In vivo nose-to-brain delivery of the hydrophilic antiviral ribavirin by microparticle agglomerates. Drug Delivery, 25, 376–387.
54. Ravikumar, R., Balan, R., Ganesan, N., & Thiruvengadam, D. (2015). Recent modalities in drug delivery via inhalation therapy: An advanced treatment strategy for pulmonary carcinoma. International Journal of Pharmacy and Pharmaceutical Sciences, 7, 8–21.
55. Mosab, A. (2025). Approaches to achieve an oral controlled release drug delivery system using polymers: A recent review. International Journal of Pharmacy and Pharmaceutical Sciences, 7, 16–21.
56. Özer, A. Y. (1990). The importance of intranasal route for application of drugs and nasal drug delivery systems. Pharmaceutical Journal of Turkey Pharmaceutical Association, 30, 136–147.
57. Hughes, B. L., Allen, D. L., Dorato, M. A., & Wolff, R. K. (1993). Effect of devices on nasal deposition and mucociliary clearance in rhesus monkeys. Aerosol Science and Technology, 18, 241–249.
58. Knoch, M., & Finlay, W. H. (2002). Nebulizer technologies. In M. Rathbone, J. Hadgraft, & M. Roberts (Eds.), Modified-release drug delivery technology (pp. 849–856). New York: Marcel Dekker.
59. Inagaki, M., Sakakura, Y., Itoh, H., Ukai, K., & Miyoshi, Y. (1985). Macromolecular permeability of the tight junction of human nasal mucosa. Rhinology, 23, 213–221.
60. Hickey, A. J. (2004). Pharmaceutical inhalation aerosol technology (2nd ed.). New York: Marcel Dekker.
61. Ashurst, I., Malton, A., Prime, D., & Sumby, B. (2000). Latest advances in the development of dry powder inhalers. Pharmaceutical Science & Technology Today, 3(7), 246–256.
62. Hussein, N. R., Omer, H. K., Elhissi, A. M., & Ahmed, W. (2020). Advances in nasal drug delivery systems. In Advances in medical and surgical engineering (pp. 279–311
63. Corbo, D. C., Liu, J. C., & Chien, Y. W. (1990). Characterization of the barrier properties of mucosal membranes. Journal of Pharmaceutical Sciences, 79, 202–206.
64. Bawarshi, R. N., Hussain, A., & Crooks, P. A. (1989). Nasal absorption of 17α-ethinyloestradiol in the rat. Journal of Pharmacy and Pharmacology, 41, 214–215.
65. Lee, V. H. L. (1988). Enzymatic barriers to peptide and protein absorption. CRC Critical Reviews in Therapeutic Drug Carrier Systems, 5, 69–97.
66. Alagusundaram, M., Deepthi, N., Ramkanth, S., Angala Parameswari, S., Mohamed Saleem, T. S., Gnanaprakash, K., Thiruvengadarajan, V. S., & Madhusudhana Chetty, C. (2010). Dry powder inhalation systems. International Journal of Research in Pharmaceutical Sciences, 1(1), 34–42.
67. Jorissen, M., & Bessems, A. (1995). Study on nasal physiology. European Archives of Oto-Rhino-Laryngology, 252, 451–454.

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