Chapter 02

Nanoparticle Formulation in Nasal Drug Delivery

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ABSTRACT

Nasal drug delivery has emerged as an effective strategy for administering therapeutic drugs, with various benefits over traditional oral and parenteral methods. This chapter gives a detailed overview of nanoparticle formulation options for nasal drug delivery systems, with an emphasis on improving delivery and therapeutic effectiveness. The chapter provides a comprehensive discussion of nasal architecture and the physiological factors that influence nasal medication absorption, such as paracellular and transcellular transport. It then delves into nanoparticle selection and manufacturing techniques, focusing on polymer media, affinity chromatography, and sustainability metrics for particle selection, as well as nanoimprint lithography, milling, homogenization, and membrane contactor techniques for nanoparticle production. The chapter also looks at new developments in nanoparticle research, such as nose-to-brain medication administration, individualized dosage techniques, and the creation of novel delivery systems. Furthermore, the chapter discusses prospective developments in nasal drug administration, including liquid and powder formulations, emergency medicine delivery, and customized patient-specific formulations. Overall, this chapter provides a complete and current review of nanoparticle composition in nasal drug delivery systems, making it a useful resource for researchers, pharmaceutical scientists, and healthcare professionals wanting to harness this potential delivery method.

KEYWORDS
Nanoparticles, Drug delivery, Nasal administration, Therapeutics, Nano-formulation, Drug development

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INTRODUCTION

Nasal administration, commonly referred to as snorting, is a method of administering medications that involves inhaling them through the nose. It can be either topical or systemic administration, since the medications administered locally might have solely local or systemic effects, such as ibuprofen or Tylenol for headaches and severe toothaches. Systemically active pharmaceuticals accessible as nasal sprays include migraine meds, overdose and seizure rescue medications, nicotine replacement, and hormone therapy.

Nasal mucosa may be a more effective route for medication absorption than the gastrointestinal system due to its greater permeability and neutral pH. Nasal mucus causes less dilution than stomach contents. Nasal therapy, commonly known as "NASAYA KARMA," is a recognized treatment in Ayurvedic Indian medicine (Chien and Chang, 1987; Jadhav et al., 2007; Krishnamoorthy and Mitra, 1998).

Nasal delivery is a promising technique for the following reasons: it allows for lower doses, quicker attainment of therapeutic blood levels, quicker onset of pharmacological activity, and drug delivery directly to the brain via the olfactory nerve. The nose's large surface area for drug absorption is due to the numerous microvilli covering its epithelial surface. The subepithelial layer is highly vascularized. However, the nose's major function is olfaction, which warms and humidifies inspired air while filtering airborne particulates.

Drugs absorbed from the nasal cavity must pass through the mucus layer, which is the initial stage of absorption. Small, uncharged medications can easily flow through this barrier, but larger, charged substances are more difficult to cross. Mucin, the main protein in mucus, binds to solutes and inhibits their diffusion. Environmental factors such as pH and temperature can cause structural changes in the mucus layer (Illum, 1987). Several absorption processes have been developed, however, only two are widely employed, including:

First Mechanism

The process includes slow and passive aquatic transfer, often known as the paracellular pathway. Intranasal absorption exhibits an inverse log association with the molecular weight of water-soluble molecules. Drugs with a molecular weight of above 1000 Daltons have low bioavailability (Aurora, 2002).

Second Mechanism

This method of transfer, also known as the transcellular process, uses a lipoidal pathway. It transports lipophilic medicines at varying rates according on their properties. Drugs can permeate cell membranes via carrier-mediated transport or tight junction opening (Aurora, 2002).

The nasal cavity is lined by a thin mucosa that is highly vascularized (Proctor and Andersen, 1982). As a result, a medication molecule can be swiftly transported across a single epithelial cell layer and into the systemic bloodstream without first passing via the liver and the intestine. For smaller pharmacological molecules, the effect is usually achieved in 5 minutes or less (Ghori et al., 2015). If a rapid effect is required or if the medication is significantly destroyed in the intestines or liver (Fransén, 2008) medicines that are poorly absorbed orally can also be administered this way.

Large-molecule drugs can also be delivered directly to the brain via the intranasal route, which follows the olfactory and trigeminal nerves, allowing for widespread central distribution throughout the central nervous system with minimal exposure to blood (Jansson, 2004; Thorne et al., 2004; Thorne et al., 1995). This form of brain delivery was functionally shown in humans in 2006, employing insulin, a big peptide hormone that works as a nerve growth factor in the brain (Reger et al., 2006).

Olfactory Transfer

The adult human nasal cavity has around 20 mL capacity (Baig and Khan, 2014). The olfactory epithelium is located in the upper posterior region and spans roughly 10 cm2 of the human nasal cavity. The olfactory epithelium's nerve cells extend into the brain's olfactory bulb, establishing a direct connection between the brain and the outside world.

However, if drugs can pass through the olfactory nerve cells, they may bypass the BBB and reach the brain directly (Costantino et al., 2007). Drugs are believed to enter the brain through olfactory nerve cells or the cerebrospinal fluid, either slowly or quickly (Illum, 2004; Mathison et al., 1998). Olfactory transfer might theoretically be utilized to administer medications with a central nervous system impact, such as those used to treat Parkinson's or Alzheimer's disease.

Nanoparticles in Drug Delivery

According to the National Nanotechnology Initiative (Kromhout et al.), nanoparticles are tiny structures, usually between 1 and 100 nanometers in size.

These super small particles, called nanocarriers (liposomes, dendrimers), have special properties that make it easier for cells to take them in. That's why they're used as delivery tools for bioactive compounds (Wilczewska et al., 2012).

The purpose of nanoparticle encapsulating drugs is to enhance their targeted delivery to specific cells, minimize toxicity to non-target organs, and ultimately elevate the therapeutic index. This involves developing nanoparticles that are persistent and specific to their intended targets, thus optimizing the effectiveness of drug treatment while minimizing adverse effects on other organ systems (De Jong and Borm, 2008).

Characteristics of Nanoparticles

Nanoparticles have two major types characteristics

- Physical characteristics
- Chemical characteristics

Physical Characteristics

Nanoparticles have various physical characteristics like, optical, mechanical and electrical characteristics (Singh et al., 2020).

Additionally, properties like hydrophilicity, hydrophobicity, suspension and settling contribute to their application in everyday items (Khan and Hossain, 2022).

Optical Characteristics

The optical characteristics of nanoparticles are quite fascinating. These include properties like hue, light infiltration, reflection and UV sorption. These properties are size-dependent that are exclusive to nanoparticles not observed in bulk materials. Nanoparticles have a intense UV-visible extinction peak, which adds to their unique optical characteristics (Peng et al., 2016).

Mechanical Characteristics

The mechanical characteristics of nanoparticles are as these encompass characteristics like elasticity, tensile strength, hardness, and flexibility (Guo et al., 2013).

Magnetic and Electrical Characteristics

The magnetic and electrical characteristics of nanoparticles are characterized by their conductivity, semi-conductivity, and resistivity (Nongjai et al., 2012).

Chemical Characteristics

The chemical attributes of nanoparticles are crucial in deciding their applications. Nanoparticles are characterized by a pronounced UV-visible extinction band, which enhances their special optical features. The unique properties of nanoparticles, including antibacterial, disinfectant, and toxic characteristics enable their use in various biological and environmental applications (Khan et al., 2019).

The chemical characteristics of nanomaterials are affected by their size, and these characteristics change as the size varies. Smaller nanomaterials have a higher number of atoms on their surface than those in bulk materials, which leads to increased reactivity. Here are a few key points about these chemical characteristics:

- The abundance of surface atoms in nanomaterials significantly impacts their behavior. With up to half of the atoms located on the surface, nanomaterials exhibit enhanced properties like electrical transport compared to bulk materials.
- The large number of surface atoms also results in higher average energy in nanomaterials. This leads to increased catalytic activity, making nanomaterials more chemically active per exposed surface atom. In contrast, in bulk materials there is decrease in catalytic activity.
- Nanomaterial surfaces can attract impurities, and the collisions across nanoparticles and these impurities based on the nanomaterial's structure and the type of chemical bonding involved (Fubini et al., 2010).

Advantages of Nanoparticles

The advantages of nanoparticles over other drug delivery systems are:

- One of the benefits of utilizing nanoparticles as a drug delivery system is the capability to control and sustain the release of the drug during transportation and at the targeted site. This controlled release helps to alter the distribution of the drug within the body organs and subsequently enhances the clearance of the drug (Singh et al., 2011).
- Nanoparticles allow for the incorporation of the drug into the system without undergoing any chemical reactions (Lata et al., 2017).
- The characteristics of controlled release and drug degradation can be easily adjusted and modified to meet specific requirement (Saad et al., 2012).
- Efficient drug utilization is ensured, leading to an enhanced bioavailability of the drug at targeted sites (Brewer et al., 2011).
- Patient convenience and compliance are enhanced while simultaneously improving the therapeutic efficacy of the drug compared to conventional systems (Brewer et al., 2011).
- Nano particles can be easily prepared (Shinde et al., 2012).
- Chances of toxicity are less (Goldberg et al., 2011).
- Doses of drug are smaller (Zhao et al., 2010).
- Nanoparticles exhibit remarkable reactivity, characterized by distinctive physicochemical attributes, including a compact and manageable size, coupled with a substantial surface-to-mass ratio (Singh et al., 2011).
- They are also recognized as suitable options for transporting vaccines, contraceptives, and specific antibiotics to targeted areas (De Oliveira et al., 2014).

Nasal Drug Delivery Challenges

Mucociliary Clearance

The mucus layer covering the nasal epithelium is moved towards the nasopharynx by means of ciliary beating, which is how the nasal mucociliary clearing system works. Its main goal is to protect the respiratory system from potential injury from chemicals breathed. Through the coordinated activity of ciliated cells, the mucociliary clearance system of the nasal cavity effectively captures and transfers inhaled particles. These cells have many cilia, which are motile projections that are around 0.3 μm wide and 5 μm long. The mucus layer is propelled by the cilia, which beat at a frequency of around 1000 beats per minute, or 12–15 Hz. The cilia are divided into three layers: an upper gel layer, a more watery periciliary liquid layer, and a surfactant layer positioned in between. Effective clearance of trapped particles is ensured by the structural contact between the cilia and nasal mucus, which transports particles to the throat at a pace of 8–10 mm/h (Marttin et al., 1998). The physical properties of mucus and the healthy operation of cilia are prerequisites for effective mucociliary clearance. These factors can be impacted by drugs that alter ciliary beat frequency (CBF). Thus, using a photoelectronic approach, researchers examined the effect of preservatives on ciliary beat frequency (Gizurarson, 2015). Many approaches have been developed to overcome the challenges posed by mucociliary clearance in nasal medication administration. These include the creation of mucoadhesive drug delivery systems with the goal of prolonging the duration of medication residence in the nasal cavity. Additionally, the use of liposomes or nanoparticles protects medications against mucociliary clearance. Moreover, permeation enhancer integration improves medication absorption via the nasal epithelium. Furthermore, advancements in the design and administration of nasal medication delivery devices strive to enhance drug deposition and dispersion within the nasal cavity, hence maximizing therapeutic results (Batts et al., 1990). Researchers

have developed a number of techniques to get around the problems caused by mucociliary clearance in nasal medication administration. Developing mucoadhesive medication delivery devices that stick to the nasal mucosa is one useful strategy. These formulations stay on the nasal epithelium longer, increasing the amount of time medications stay in the nasal cavity and improving drug absorption (Illum, 2012). Apart from mucoadhesive systems, the use of liposomes or nanoparticles is another effective tactic. These nanocarriers have the ability to encapsulate medications, protecting them from the mucociliary system's quick clearance. Nanoparticles and liposomes increase medication stability and bioavailability and prevent drug breakdown and clearance, which increases therapeutic efficacy (Illum, 2012). Additionally, it has demonstrated a great deal of promise to overcome mucosal barriers in nasal medication formulations by including permeation enhancers. medicines are better transported into the systemic circulation when permeability enhancers help absorb medicines via the nasal epithelium. This strategy has been very successful in increasing the bioavailability of poorly soluble medications, resulting in improved therapeutic effects (Vllasaliu et al., 2014). The development of nasal medication delivery devices and their administration methods has also made a substantial contribution to the resolution of mucociliary clearance issues. For example, nasal sprays and nasal inserts have been created to maximize medication dispersion and deposition inside the nasal cavity. By guaranteeing accurate dosage and boosting patient compliance, these cutting-edge delivery methods seek to increase the efficacy of medication delivery (Merkus et al., 2006).

Nasal Permeability

The ability of a medication to pass through the nasal mucosa and into the bloodstream is known as nasal permeability. The nasal mucosa is a complex barrier that regulates molecular transport. It is made up of mucus layers, tight junctions, and epithelial cells. Numerous variables, including the integrity of the nasal epithelium, the presence of efflux transporters, and the physicochemical properties of medicines (such as molecular weight and lipophilicity), affect nasal permeability. All of these variables work together to determine how well drugs are absorbed through the nasal route (Merkus et al., 2006). The ability of a medication to pass through the nasal mucosa and into the bloodstream is known as nasal permeability. The nasal mucosa is a complex barrier that regulates molecular transport. It is made up of mucus layers, tight junctions, and epithelial cells. Numerous variables, including the integrity of the nasal epithelium, the presence of efflux transporters, and the physicochemical properties of medicines (such as molecular weight and lipophilicity), affect nasal permeability. All of these variables work together to determine how well drugs are absorbed through the nasal route (Illum, 2012). The limitations imposed by restricted nasal permeability provide challenges for nasal medication administration, necessitating creative approaches to enhance drug absorption. Surfactants and cyclodextrins are two examples of permeability enhancers that have become effective treatments because they temporarily damage the nasal epithelium, allowing medications to pass through more easily (Costantino et al., 2007). Prodrug techniques include chemically modifying medications to increase their lipophilicity or to target specific transport systems, which improves nasal permeability (Dhuria et al., 2010). Various approaches have been developed to tackle the challenges associated with limited nasal permeability. One such these is the use of permeation enhancers, which allow drugs to be absorbed more easily by momentarily disrupting the nasal epithelium's integrity. Surfactants, bile salts, and cyclodextrins are a few examples of these enhancers that have been investigated for their effectiveness in nasal medication delivery (Lee et al., 2000). Another strategy is to use prodrug strategies, in which the initial medication is chemically altered to increase its lipophilicity or to target specific transport systems in the nasal mucosa. Prodrugs can increase a drug's permeability and avoid efflux transporters, which improves the absorption of the medication (Illum, 2012). Furthermore, the development of innovative medication delivery technologies, such as liposomes, micelles, and nanoparticles, offers a possible remedy for increasing nasal permeability. These cutting-edge delivery methods have the power to increase a drug's stability and solubility, which will increase its absorption. Moreover, they facilitate the prolonged release of medications, lengthening the duration of their retention in the nasal cavity (Salamat-Miller et al., 2005).

Nanoparticle Formulation

Selection of Nanoparticle Materials

The selection of nanoparticles according to their properties is crucial for creating accurate and complex nanodevices that can be used for quantum sensing, photon generation, and quantum information processing. Nanoparticles are selected based on their quantum mechanical properties, by polymer media, affinity chromatography, and sustainability matrices (Fujiwara et al., 2021)

Polymer Method

By utilizing polymers as a medium, researchers can manipulate nanoparticles' shape, size, and surface characteristics, enabling customized designs for particular applications. When nanoparticles are soluble in the polymer medium their size becomes critical if the nanoparticles are sufficiently small, they disperse freely within the polymer brush film. If nanoparticles are large these nanoparticles disperse to the bottom which varies inversely to their volume. For instance, if nanoparticles are insoluble in the polymer, a different behavior emerges. The brush stabilizes the dispersion of the nonwetting particle at the surface of the film. The brush then selects the final morphology of the nanoparticle aggregates (Kim and O'Shaughnessy, 2002).

Affinity Chromatography

The solution lies in affinity chromatography. The nanoparticle sample is applied to a column containing a complementary binding substance. Under conditions favoring specific binding, the target nanoparticles attach to the ligand (binding substance). Unbound material is washed out of the column. Finally, the bound target nanoparticles are recovered by changing conditions to favor elution. One of the main challenges associated with this technology is forming a wide range of binding sites with varying affinities (Guerreiro et al., 2009).

Quantum Mechanical Properties

Nanoparticles like nanocrystals, nanoparticles of carbon and metals have great importance because of their quantum mechanical properties semiconductor quantum dots and diamond nanoparticles have distinct optoelectronic properties because of the quantum confinement and quantum resonances they exhibit. These properties affect the optical forces that act on the nanoparticles, including the gradient force, dissipative scattering force, and quantum resonant absorption force (Fujiwara et al., 2021).

By Sustainability Metrics

Metrics of unattainability play a crucial role in assessing various aspects such as the utilization of resources, consumption of energy, production of waste, and the possible impacts on health and the ecosystem (Naidu et al., 2008).

Manufacturing Techniques

A two-step process is followed by many methods for manufacturing nanoparticles. The first step involves the preparation of an emulsifying system and the second step is accomplished by the formation of the nanoparticles. In the second step, nanoparticles are formed by the polymerization of monomers or gelation/precipitation of the polymers. It's during this second step that the nanoparticles take shape (Vauthier and Bouchemal, 2009). Nanofabrication is the technique to manufacture nanoparticles. The nanoimprint lithography (NIL) is the well-developed of the alternative nanofabrication techniques. NIL is a cool fabrication technique that's malleable, low-cost, and compatible. It has some superiority over traditional nanofabrication methods, and there are different variations of NIL. One of these differences is called step and flash imprinting lithography (SFIL), where instead of applying pressure, a process is used called UV polymer curing process (Baron et al., 2007). The other methods for nanoparticle manufacturing are milling and homogenization. Wet milling is a important technique for producing nanoparticles in which the concentrated drug is dispersed along with the milling balls in an aqueous or non-aqueous medium. This process, also known as media milling, is more effective than dry milling. The procedure of wet milling method is shown in Fig. 1.

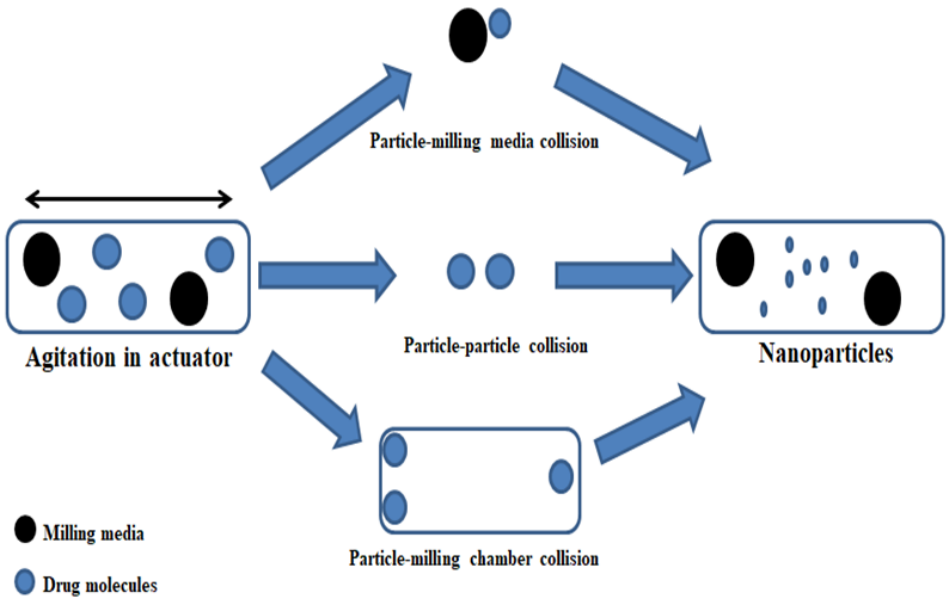

Fig. 1: Wet milling method.

The method for creating nanoparticles High-pressure homogenization. It includes subjecting the material to high pressure, which leads to reduction of particle size. This technique is particularly beneficial for achieving uniform particle sizes and enhancing bioavailability. Ultrasonic homogenization breaks down larger particles into smaller ones by ultrasonic waves. It's effective for creating stable nanoparticle suspensions (Table 1). The ultrasonic energy disorder agglomerates and promotes uniform dispersion (LLER et al., 2006). Another technique is the membrane contactor technique. In this method, a polymer solution is spread onto a stretched membrane, and as the solvent evaporates, the polymer forms a thin

film on the membrane. The film then undergoes contraction, directing towards the formation of nanoparticles (Vauthier and Bouchemal, 2009).

Table 1: Formulation used for nanoparticle preparations by the membrane contactor technique (Vauthier and Bouchemal, 2009)

Methods	Organic phase	Aqueous phase	Type of nanoparticles
Nanoprecipitation	Acetone (0.6 L) PCL (15 g)	Water (1.2 L) Tween® 20 (2.04 g)	Nanospheres
	Acetone (0.6 L) PCL (2.4-3 g) Labrafac® hydro (9.6-12 mL)	Water (1.2 L) Tween® 80 (2.8-4.8 g)	Nano capsules
	Water pH>5.2 Eudragit® L100	Water pH<2 PVA	Nanospheres
	Water pH<5.2 Eudragit® E100	Water pH>11 PVA	Nanospheres
Interfacial polycondensation combined with spontaneous emulsification	Acetone (0.6 L) Span® 80 (1.2 g) Oil: hexyl laurate (6 g) Lipophilic monomer (3.3 g)	Water (1.2 L) Tween® 20 (2.04 g) Hydrophilic monomer (19.65 g)	Nano capsules

Modification of Surface for Enhanced Delivery

Modification of the nanoparticles' surface is a critical strategy to enhance their performance in drug delivery systems. The physicochemical characteristics like surface composition and superficial charge of nanoparticles significantly affect their uptake efficiency and biocompatibility. By modifying the NP surface, we can improve their biocompatibility and cellular uptake. The polymer coating enhances the stability and reduces toxicity. The coating with polyethylene glycol (Stuen et al.) increases circulation time and reduces immune response (Natarajan and Selvaraj, 2014). Surface modification is a basic process for improving the transportation of nanoparticles and effectively inhibiting imprecise interactions with biological molecules, thus preventing early clearance. An example of this idea is using compatible-with-life materials to enclose tiny particles, creating a shield against the body's defense system. By changing the surface, nanoparticles can be accurately guided to specific cells or tissues by attaching ligands like antibodies or peptides to their surface. These ligands can bind to receptors on the target cells, thereby enhancing the efficiency of drug delivery while reducing adverse effects associated with systemic administration. This targeted approach aims to maximize efficacy and minimize unwanted impacts (Abdelkawi et al., 2023).

Future Perspectives

Emerging Trends in Nanoparticle Research

The next years will see a range of new products in the market. An underexplored research topic is the administering medication via the nasal passage allows for direct delivery to the central nervous system by way of the olfactory or trigeminal nerves located in the nasal cavity, circumventing the blood-brain barrier. The number of drugs that reach the CNS via the nasal route is usually very low, with less than 1% of the dose applied in the nasal cavity. The primary obstacle in administering treatments from the nose to the brain is effectively reaching the olfactory area within the nasal passages, which is difficult to access, and improving the movement of peptides and proteins through the olfactory membrane. There is a need for a nasal apparatus that can precisely target the olfactory area and a delivery mechanism that includes both a nasal absorption enhancer and a bio-adhesive substance to boost the transport of drugs into the central nervous system. Recently, some studies have reported new methods to enhance the brain 'bioavailability' of drugs by using innovative delivery approaches and absorption enhancers (Illum, 2012). Intranasal drug delivery is a rapidly growing research area that can be combined with therapeutic drugs to treat different diseases of the respiratory system, nasal cavity, and brain. Literature research in this field preceded patent applications, which started around 1974. Nasal devices and mechanisms were important patent clusters. The active ingredient analysis revealed that the FDA approved more nasal drugs after 1982, mainly small-molecule drugs. However, there are still many challenges in basic research that need further attention. One major problem is the changeability in drug absorption among individuals due to the compounded and variable nasal cavity (Lalan et al., 2019). Further investigation is essential to understand the processes of absorption and clearance included in nasal medication delivery to the brain, especially for pharmaceuticals that follow the intranasal route to the brain. Another challenge is the limited drug-loading volume of nasal DDS due to the small surface area of the nasal cavity for absorption. Ingenious delivery methods, including nanoparticles, liposomes, and micro-emulsions, are presently in development to improve the solubility and permeability of drugs. Safety and bearability of nasal DDS are important considerations, given the sensitivity of the nasal cavity. Some materials related to DDS may interact with normal clearance or result in unwanted immunogenicity that requires careful evaluation for long-duration safety. The development of safe and well-accepted nasal DDS is important for clinical application. In clinical practice, it is important to address the problems associated with enhancing the production of drug delivery systems (DDS) while maintaining uniform standards.

Ultimately, the progress of intranasal devices that are both easy to use and dependable is important for the effective administration of drug delivery systems (DDS) and to ensure high levels of patient compliance (Xu et al., 2024). Nanomedicine will benefit from the future development and enhancement of functionalized polymeric nanoparticles, which can help cure serious diseases like cancer with fewer adverse effects. Ongoing research on functionalized nanoparticles will increase the methods of disease diagnosis, treatment, and prevention. Research should objective to devise a simple, efficient, and direct production and scaling-up technique for nanoparticles. Regulatory guidelines should be established to ensure the safety of nanoparticles for humans and the environment (Sur et al., 2019). Nanoparticles hold significant potential for advancing various biomedical fields, notably in diagnosing diseases, enabling early detection, and imaging at the cellular and deep tissue levels, facilitating drug delivery, and serving as versatile therapeutic agents. Molecular medicine is currently focused on creating new and innovative tools for early-stage disease diagnosis and point-of-care diagnostics. The goal is to develop advanced techniques that can detect diseases at an early stage and provide faster and more convenient diagnostic options. Personalized medicine is achieving a lot of attention, and the integration of nanotechnology has the potential to bring about some amazing outcomes. In the coming years, multifunctional nanoparticles are expected to play a vital role in biomedical applications, such as disease diagnosis and drug delivery. This could even lead to changes in the traditional business model of pharmaceutical industries (Vallabani and Singh, 2018).

Potential Innovations in Nasal Drug Delivery

Nasal delivery is an area for innovation and advancement. Advancements in nanotechnology are unfolding within an environment characterized by swift technological advancements. For small and medium-sized enterprises , which are often the birthplace of early-stage innovations, it is challenging to stay abreast of the relentless stream of research and information that is pertinent to their process of innovation (Kraegeloh et al., 2018). Researchers are actively developing innovative liquid and powder nasal drug delivery systems. Formulations need to address drug solubility, permeation, stability, and mucoadhesive properties. Advancements in characterization methods are essential for nasal formulation development. Researchers explore techniques to assess drug behavior in vitro, ex vivo, and in vivo. Nasal drug delivery offers a direct route to the brain. Researchers investigate strategies for delivering therapeutics to treat neurological disorders (Garcia-Reyero et al., 2014). Nasal vaccines can stimulate mucosal immunity. Innovations aim to enhance vaccine effectiveness and patient compliance (Jabbal-Gill, 2010). Nasal delivery could be a game-changer for COVID-19 treatments. Researchers explore antiviral drugs and vaccines via this route. Rapid nasal delivery of emergency medications (e.g., for anaphylaxis) is gaining attention. Innovations focus on ease of use and precise dosing. Researchers investigate bypassing the blood-brain barrier and delivering drugs directly to the brain. This approach holds promise for treating neurological conditions. Nasal formulations for CNS disorders (e.g., migraine, Alzheimer's) are being explored. Innovations aim to improve drug availability and patient adherence. Tailoring nasal drug delivery to individual patients is an exciting frontier. Innovations may include patient-specific formulations or dosing regimens (Illum, 2002).

Conclusion

Nasal delivery is considered a promising technique for its various advantages. It allows for lower doses, quicker attainment of therapeutic blood levels, quicker onset of pharmacological activity, and drug delivery directly to the brain via the olfactory nerve. Nanoparticles for nasal administration have better physical and chemical properties that enhances their bioavailability. This innovative delivery system can be utilized to enhance the effectiveness of drug delivery by ensuring precise dosing and improving patient compliance. Moreover, it is a targeted approach that can optimize efficacy and minimize unwanted impacts. The next years will see a range of new products in the market. Researchers are actively developing innovative liquid and powder nasal drug delivery systems. This technique will be a gateway to further innovations which may include patient-specific formulations or dosing regimens and the treatment will be patient-oriented instead of drug-oriented. In the coming years, multifunctional nanoparticles are expected to play a major role in biomedical applications, such as disease diagnosis and drug delivery.

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