



MODERN APPROACHES TO ORAL DRUG DELIVERY: MUCOADHESIVE, BIOADHESIVE, AND NANOCARRIER-BASED SYSTEMS

Dr. Balasiddharth S*

Private Practitioner, Chennai, India.

ABSTRACT

Drug delivery systems in oral health have seen significant advancements in recent years, driven by the need to improve the effectiveness, bioavailability, and patient compliance of oral therapies. Traditional drug delivery methods face challenges such as poor drug retention, instability, and inadequate therapeutic concentrations at the target site. To overcome these limitations, innovative drug delivery technologies have been developed, including controlled-release systems, Nano carriers, mucoadhesive formulations, and bio adhesive systems. These advancements enable localized delivery, sustained drug release, and improved targeting of active ingredients to specific oral tissues, such as the gingiva, mucosa, and periodontal pockets. Recent research has focused on developing drug delivery systems for the management of various oral health conditions, including periodontal disease, oral infections, oral cancer, and dry mouth (xerostomia). Nanotechnology, in particular, has shown great promise in enhancing drug solubility, stability, and permeability across oral mucosa, leading to improved therapeutic outcomes. The integration of antimicrobial agents, anti-inflammatory drugs, and pain-relief formulations into these systems has further expanded their clinical applications. This review provides a comprehensive overview of the recent advancements in drug delivery systems for oral health, discussing the various technologies, materials, and clinical applications. It also explores the challenges and future directions in this field, highlighting the potential for further innovation in developing safer, more efficient, and patient-friendly drug delivery systems for oral care.

Key words:- Oral cancer, pharmacological approaches, squamous cell carcinoma, chemotherapy, targeted therapy.

Access this article online

Home page:

<http://www.mcmed.us/journal/ajomr>

Quick Response code



Received:09.02.2026

Revised:05.03.2026

Accepted:11.04.2026

INTRODUCTION

The field of oral health has witnessed remarkable advancements in drug delivery systems, spurred by the growing demand for effective treatments to address a wide range of oral conditions. Traditional oral drug delivery methods, such as systemic administration via tablets or capsules, often fail to achieve sufficient drug concentrations at the site of action, leading to suboptimal therapeutic outcomes.

Corresponding Author

Dr. Balasiddharth S.

Moreover, these conventional methods can result in systemic side effects, necessitating the development of more targeted and localized drug delivery systems.

Recent innovations in drug delivery technologies have focused on overcoming these challenges, aiming to provide more controlled, sustained, and site-specific release of therapeutic agents in the oral cavity. Recent innovations in drug delivery technologies have focused on overcoming these challenges, aiming to provide more controlled, sustained, and site-specific release of therapeutic agents in the oral cavity. Among

the various approaches, controlled-release systems, such as sustained-release tablets, films, and gels, offer the advantage of prolonged drug release, ensuring therapeutic levels are maintained for extended periods without the need for frequent administration[1]. These systems are particularly useful for chronic oral conditions like periodontal disease, where continuous drug delivery is essential for effective treatment. Nanotechnology has also emerged as a game-changer in oral drug delivery, with Nano carriers such as liposomes, solid lipid nanoparticles, and dendrimers enabling improved solubility, stability, and targeted delivery of drugs to specific oral tissues, including the mucosal lining, gingiva, and periodontal pockets. These Nano carriers can also be designed to enhance the permeation of drugs across the oral mucosa, a crucial factor for ensuring adequate drug absorption. Another promising approach involves the development of mucoadhesive formulations, which adhere to the oral mucosa, allowing for prolonged contact with the drug and improving drug retention at the site of action. Bio adhesive systems have shown particular promise in treating localized infections, such as those seen in the management of oral candidiasis or bacterial infections, by ensuring the targeted delivery of antimicrobial agents directly to the affected areas. Furthermore, there has been a growing focus on combining multiple therapeutic agents in a single drug delivery system, such as incorporating both anti-inflammatory and antimicrobial drugs for the management of periodontal disease or combining analgesics with anticancer agents for the treatment of oral cancers[2]. While these advances have significantly improved the potential for localized and sustained drug delivery, challenges remain, including the need to overcome issues related to drug stability, patient compliance, and the development of cost-effective, scalable production methods. The future of oral drug delivery systems holds exciting possibilities, as continued research and innovation in materials science, nanotechnology, and formulation strategies promise to further revolutionize the treatment of oral diseases and improve patient outcomes.

The Need for Advanced Drug Delivery in Oral Health

The need for advanced drug delivery systems in oral health has become increasingly important due to the limitations of conventional oral drug administration methods. Oral health conditions, such as periodontal disease, oral infections, and oral cancer, require localized treatment to effectively target the affected tissues while minimizing systemic exposure and side effects. Traditional drug delivery methods, such as oral tablets and syrups, often lead to poor bioavailability, irregular drug distribution, and a lack of sustained therapeutic levels at the target site. This results in frequent dosing

and reduced patient compliance, particularly for chronic oral conditions that require long-term management. Advanced drug delivery systems offer a solution to these challenges by enabling localized, controlled, and sustained release of therapeutic agents directly at the site of action, ensuring higher drug concentrations at the target tissues and reducing the need for frequent administration. These systems include topical formulations, mucoadhesive gels, films, and nanoparticles, which are designed to enhance drug retention and improve the efficiency of drug absorption through the oral mucosa[3]. Additionally, advanced systems can facilitate the targeted delivery of drugs to specific oral tissues, such as the gingiva or periodontal pockets, enhancing therapeutic efficacy while minimizing damage to surrounding healthy tissues. With the growing prevalence of oral diseases, particularly in aging populations and individuals with systemic conditions like diabetes, there is a heightened demand for effective treatments that address the unique challenges of oral health. By advancing drug delivery systems, it is possible to improve treatment outcomes, reduce adverse effects, and enhance patient compliance. Moreover, these innovative systems also hold promise in treating oral cancer, a disease where localized therapy is critical to improve survival rates and reduce the side effects of systemic treatments. Therefore, the development of advanced drug delivery systems in oral health is essential to meet the growing demands for more efficient, effective, and patient-friendly therapeutic options.

Oral Mucosal Drug Delivery: Challenges and Opportunities

Oral mucosal drug delivery presents unique challenges and opportunities in the field of drug administration, particularly for localized treatments of oral health conditions such as periodontal disease, oral infections, and oral cancer. The oral mucosa, though offering a relatively easy route for drug delivery, also poses significant barriers to effective drug absorption. The thick mucosal barrier, composed of epithelial cells with tight junctions, prevents large drug molecules from penetrating efficiently into underlying tissues. Additionally, the presence of saliva, which constantly washes away drugs, and the natural turnover of the mucosal epithelium, further complicate drug retention and bioavailability. These challenges often result in low drug concentrations at the site of action, necessitating the development of more efficient drug delivery systems that can overcome these barriers. Recent advancements in oral mucosal drug delivery technologies aim to enhance drug absorption and retention, including the use of mucoadhesive formulations, which adhere to the mucosal surface and provide prolonged contact time for drug release. This approach is particularly beneficial for

chronic conditions like periodontal disease, where sustained drug levels are necessary for effective treatment[4]. Additionally, the advent of nanoparticles and liposomes has provided new opportunities to improve the permeability of drugs across the mucosal barrier, enhancing their bioavailability and therapeutic effectiveness. Despite the promising potential of oral mucosal drug delivery, several challenges remain. For example, the oral mucosa's variable permeability across individuals and regions of the oral cavity can result in inconsistent drug absorption. Furthermore, the complexity of the oral environment, including the presence of food, drinks, and saliva, requires the development of drug delivery systems that can remain stable and effective under varying conditions. Nevertheless, the opportunities presented by oral mucosal drug delivery are vast, particularly for localized treatments of oral diseases, and ongoing research in this field promises to lead to more efficient and patient-friendly therapies in the near future.

Barriers to Drug Absorption in the Oral Cavity

The oral cavity presents several significant barriers to drug absorption, which pose challenges in the development of effective drug delivery systems for oral health. The first major barrier is the oral mucosa, a stratified epithelium that acts as a protective barrier to foreign substances, including drugs. This epithelium is tightly packed with keratinized cells, particularly in areas like the hard palate, which limits drug penetration. Moreover, the epithelial cells are held together by tight junctions, which further restrict the movement of larger drug molecules. In addition to the mucosal barrier, the high salivary turnover rate in the oral cavity is another obstacle to effective drug absorption. Saliva continuously washes the oral mucosa, which can quickly clear therapeutic agents from the site of action, reducing drug retention time. This necessitates frequent reapplication of drugs or the development of mucoadhesive formulations that can adhere to the mucosal surface for extended periods. Furthermore, the oral cavity's pH and enzymatic environment can also impact drug stability and solubility[5]. The acidic pH of the saliva and the presence of digestive enzymes, such as amylase and lipase, can degrade certain drugs, rendering them less effective. In addition to these physical and chemical barriers, the blood flow to the oral tissues is limited, particularly in areas like the gingiva and periodontal pockets, which can lead to inadequate drug distribution and absorption. The mucosal surface's variability in permeability across individuals and even within different regions of the oral cavity complicates the development of standardized drug delivery systems. These barriers underscore the need for advanced drug delivery technologies, such as nanoparticles, liposomes, and mucoadhesive gels, which

can enhance drug penetration, stability, and retention in the oral cavity. Overcoming these challenges requires a comprehensive understanding of the oral cavity's anatomy, physiology, and pathology, alongside the development of new materials and technologies to improve drug absorption and ensure more effective oral health treatments.

Strategies for Enhancing Drug Permeability

Enhancing drug permeability across the oral mucosal barrier is a key challenge in the development of effective drug delivery systems for oral health. Several strategies have been explored to improve the permeation of therapeutic agents through the mucosal surface and enhance their bioavailability at the target site. One approach is the use of permeation enhancers, which are compounds that temporarily disrupt the integrity of the mucosal barrier, allowing for improved drug absorption. These enhancers work by interacting with the lipid bilayer of the cell membrane, increasing the fluidity and permeability of the mucosal epithelium. Common permeation enhancers include surfactants, bile salts, fatty acids, and cyclodextrins, which can facilitate the transport of drugs across the mucosal barrier. However, the use of permeation enhancers must be carefully controlled to avoid toxicity and ensure the safety of the oral mucosa. Another strategy for enhancing drug permeability is the use of nanotechnology. Nano carriers, such as liposomes, solid lipid nanoparticles, and dendrimers, can encapsulate drugs and protect them from degradation while enhancing their ability to permeate the mucosal surface[6]. These Nano carriers can be designed to carry hydrophilic and hydrophobic drugs, improving the solubility, stability, and bioavailability of therapeutic agents. Additionally, the small size of nanoparticles allows for enhanced diffusion across the mucosal epithelium, ensuring that drugs reach the underlying tissues more effectively. Mucoadhesive formulations are also an important strategy for enhancing drug permeability. By using polymers or materials that adhere to the mucosal surface, mucoadhesive formulations prolong drug contact time, allowing for sustained drug release and improved absorption. These formulations can also help protect drugs from enzymatic degradation and dilution by saliva. In recent years, the development of stimuli-responsive drug delivery systems has gained attention as a novel way to enhance drug permeability. These systems can release drugs in response to environmental stimuli, such as pH or temperature changes, ensuring that drugs are delivered only when needed. Overall, enhancing drug permeability in oral health is essential for improving the efficacy and patient compliance of oral treatments, and these strategies hold great promise in the development of advanced drug delivery systems.

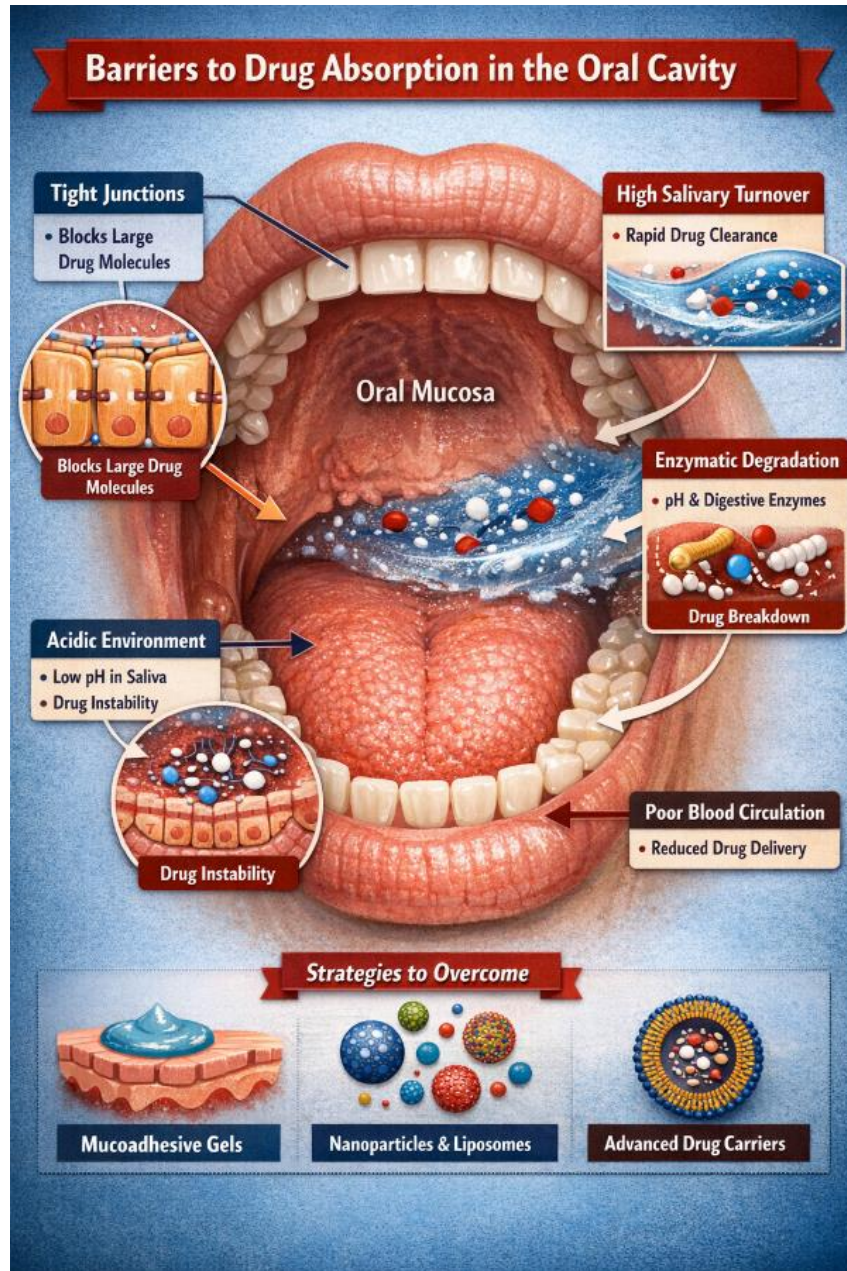


Figure:1 Barriers to Drug Absorption in the Oral Cavity

Topical Drug Delivery Systems for Oral Health: Innovations and Applications

Topical drug delivery systems for oral health have seen significant innovations, providing effective solutions for treating localized oral conditions such as periodontal disease, oral infections, and mucosal lesions. Traditional oral drug delivery methods, such as oral tablets and systemic injections, often fail to achieve high enough drug concentrations at the site of action and can cause systemic side effects. Topical formulations, on the other hand, allow for the direct application of therapeutic agents to the oral mucosa, ensuring targeted and localized

drug delivery. One of the most promising advancements in topical drug delivery is the development of mucoadhesive formulations. These systems are designed to adhere to the mucosal surfaces in the oral cavity, such as the gums, tongue, and inside of the cheeks, providing prolonged contact time and enhanced drug retention at the site of action. Mucoadhesive gels, films, and patches are commonly used for this purpose, allowing for the sustained release of drugs and improving therapeutic outcomes for conditions like periodontal disease and oral ulcers. Additionally, nanotechnology has greatly advanced topical drug delivery in oral health[7]. Nano

carriers, such as liposomes, nanoparticles, and solid lipid nanoparticles, can encapsulate drugs and protect them from degradation, improving drug stability and bioavailability. These Nano carriers can also penetrate the mucosal barrier more effectively, enhancing drug absorption and ensuring higher concentrations of therapeutic agents at the target site. Furthermore, these Nano carriers can be functionalized with targeting ligands, allowing for selective drug delivery to specific cells or tissues in the oral cavity, such as infected periodontal tissues. Another significant innovation is the development of bioactive scaffolds and hydrogels that promote tissue regeneration while delivering drugs. These systems are particularly useful for the treatment of oral wounds, lesions, and microsites, as they not only provide drug delivery but also create a favorable environment for tissue healing. Despite these innovations, challenges remain in the development of topical drug delivery systems, such as achieving optimal drug solubility, stability, and patient compliance. Nevertheless, the continued advancement of topical formulations holds great potential for revolutionizing oral health treatments, offering more effective, localized, and patient-friendly options for a range of oral conditions[2].

Liposomal and Nanoparticle Systems in Oral Health

Liposomal and nanoparticle systems have gained significant attention in oral health drug delivery due to their ability to enhance drug solubility, stability, and targeted delivery. These advanced systems offer numerous advantages over traditional drug delivery methods, particularly in addressing the unique challenges associated with oral drug administration, such as poor bioavailability, limited drug retention, and the need for sustained drug release. Liposomes, which are lipid-based vesicles, can encapsulate both hydrophilic and

hydrophobic drugs, protecting them from degradation and improving their bioavailability. Liposomal formulations are particularly useful for delivering drugs to the oral mucosa, as they can penetrate the epithelial barrier and deliver therapeutic agents directly to the target tissues. These formulations are often used in the treatment of oral infections, periodontal disease, and mucosal lesions, where localized drug delivery is critical for effective treatment. Nanoparticles, including solid lipid nanoparticles, dendrimers, and polymeric nanoparticles, offer additional advantages in oral drug delivery.[8] The small size of nanoparticles allows for enhanced diffusion across biological membranes, improving drug penetration and absorption in the oral cavity. Additionally, nanoparticles can be engineered to improve the solubility and stability of poorly water-soluble drugs, making them more effective for a wider range of therapeutic agents. The surface of nanoparticles can also be modified with specific ligands or antibodies, enabling targeted delivery to particular cells or tissues in the oral cavity, such as infected periodontal pockets or cancerous cells. This targeted approach not only enhances therapeutic efficacy but also reduces the risk of side effects by minimizing exposure to healthy tissues. Furthermore, the controlled release properties of liposomal and nanoparticle systems allow for sustained drug release over extended periods, reducing the need for frequent dosing and improving patient compliance. Despite their promising potential, challenges remain in the clinical application of liposomal and nanoparticle systems, such as the need for optimized manufacturing processes, scalability, and regulatory approval. Nonetheless, these advanced drug delivery systems hold great promise for improving the treatment of a wide range of oral health conditions, offering more efficient, localized, and patient-friendly therapeutic options[9].

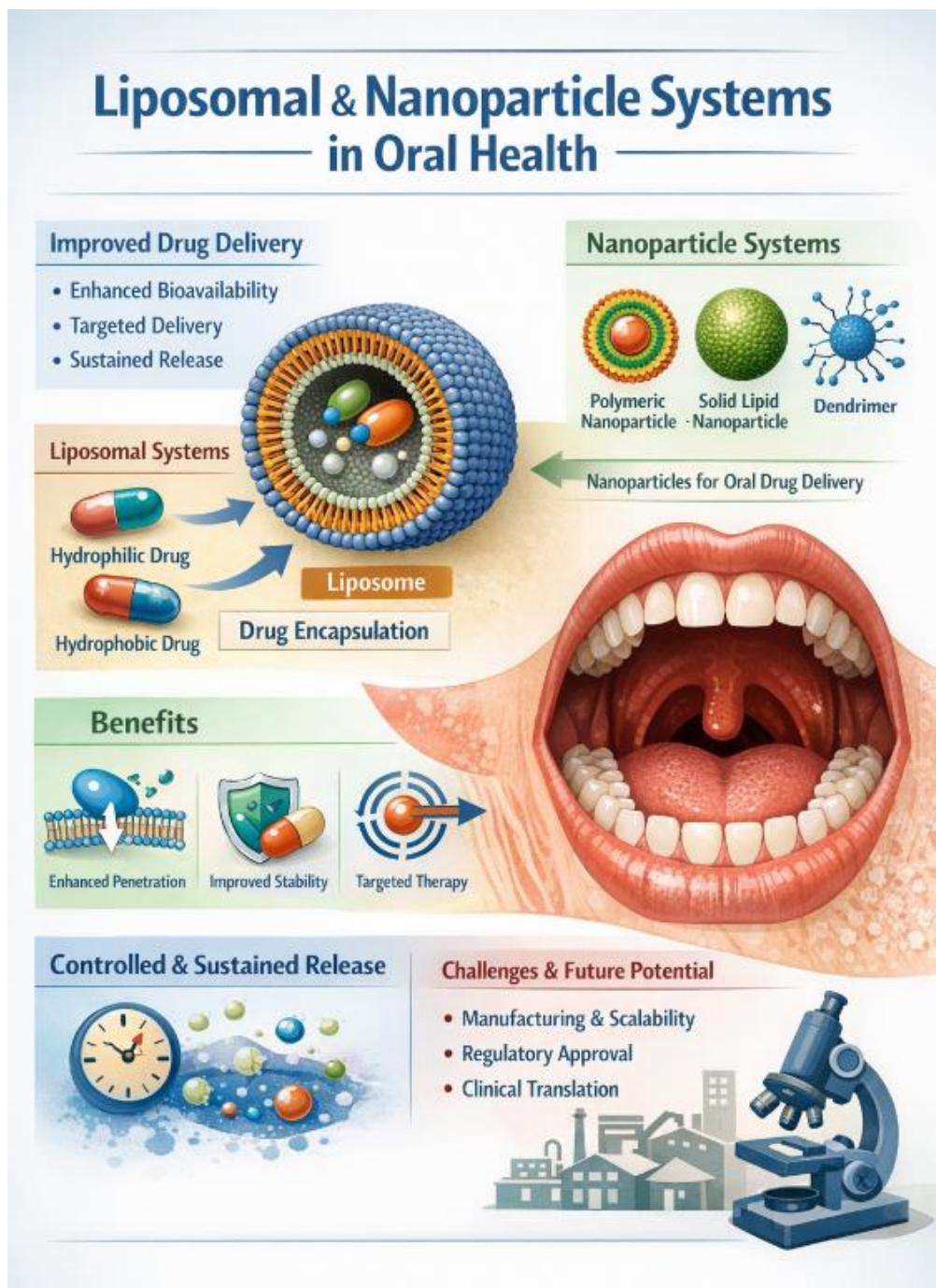


Figure 2: Liposomal and Nanoparticle Systems in Oral Health

Systemic Drug Delivery via Oral Cavity: Potential and Limitations

Systemic drug delivery via the oral cavity presents both significant potential and notable limitations in oral health management. The oral cavity offers a convenient and non-invasive route for drug administration, with the potential to provide therapeutic agents directly to the bloodstream through absorption via

the sublingual mucosa or buccal membranes. This method offers advantages over traditional oral tablets, as it bypasses the gastrointestinal tract and first-pass metabolism in the liver, allowing for faster drug onset and potentially higher bioavailability. Drugs administered through the oral cavity can reach systemic circulation more efficiently, making this route particularly useful for treating conditions that require rapid onset of action or

those that involve systemic effects. For example, sublingual delivery of certain medications, such as nitroglycerine for angina or fentanyl for pain relief, has been shown to offer faster relief compared to traditional oral administration. However, there are several limitations to systemic drug delivery via the oral cavity. The permeability of the oral mucosa is limited, with tight junctions between epithelial cells hindering the passage of larger molecules[10]. This presents challenges for the delivery of macromolecules, such as proteins, peptides, or nucleic acids, which require specialized delivery systems, such as nanoparticles or liposomes, to enhance permeability and protect them from enzymatic degradation. Additionally, the oral cavity's constantly changing environment, including saliva production, swallowing, and food intake, can affect drug absorption and retention, making it difficult to achieve consistent and reliable drug delivery. Moreover, the relatively small surface area available for drug absorption in the oral cavity limits the amount of drug that can be effectively delivered through this route. Despite these challenges, systemic drug delivery via the oral cavity holds significant potential, particularly for localized treatments of oral diseases, and advances in drug delivery technologies, such as mucoadhesive systems, nanoparticles, and liposomes, are helping to overcome these limitations and improve the feasibility and efficacy of oral cavity-based drug delivery.

Recent Advances in Nanotechnology for Oral Drug Delivery

Recent advances in nanotechnology have revolutionized oral drug delivery systems, offering new possibilities for enhancing drug solubility, stability, and targeted delivery, particularly in the treatment of oral health conditions. Nanotechnology enables the development of Nano carriers, such as liposomes, solid lipid nanoparticles, and dendrimers, which have the ability to encapsulate a wide range of therapeutic agents, including poorly water-soluble drugs, proteins, peptides, and nucleic acids. These Nano carriers protect drugs from degradation, enhance their bioavailability, and allow for controlled, sustained release, improving therapeutic efficacy while reducing systemic toxicity. One of the key benefits of nanotechnology in oral drug delivery is its ability to overcome the barriers to drug absorption in the oral cavity, such as the thick mucosal barrier and the presence of saliva, which can dilute and wash away drugs. Nanoparticles, due to their small size, can penetrate the mucosal epithelium more easily, enabling improved drug absorption and targeted delivery to specific tissues, such as the gingiva, mucosa, and periodontal pockets. Nano carriers can also be functionalized with ligands, such as antibodies or peptides, that selectively bind to specific receptors on the

surface of target cells, enhancing the specificity and effectiveness of the drug[11]. This targeted approach minimizes the impact on healthy tissues, reducing side effects and improving overall treatment outcomes. Additionally, nanotechnology allows for the incorporation of multiple therapeutic agents into a single Nano carrier, enabling combination therapies for more effective treatment. For example, combining antimicrobial agents with anti-inflammatory drugs in a single nanoparticle system can address both the infection and inflammation aspects of periodontal disease simultaneously. Despite the promising potential of nanotechnology in oral drug delivery, several challenges remain, including the need for optimized manufacturing processes, stability issues, and regulatory approval. Additionally, the safety and long-term effects of Nano carriers must be thoroughly evaluated before their widespread clinical use. Nevertheless, the ongoing development of nanotechnology-based drug delivery systems holds great promise for improving the treatment of oral diseases, offering more efficient, targeted, and patient-friendly therapeutic options.

Nanoparticles and Nano carriers in Oral Health

Nanoparticles and Nano carriers have emerged as one of the most promising innovations in oral health drug delivery, offering significant advantages over traditional delivery systems. These nanostructures, which range in size from 1 to 1000 nanometres, are capable of encapsulating both hydrophilic and hydrophobic drugs, enhancing their solubility, stability, and bioavailability. In oral health, nanoparticles are particularly useful for improving drug delivery to localized sites such as periodontal pockets, the oral mucosa, and the gingiva, where conventional oral delivery methods may fail to achieve sufficient drug concentrations. The small size of nanoparticles allows them to penetrate biological membranes more effectively, improving drug absorption across the oral mucosal barrier. Additionally, nanoparticles can be engineered to release drugs in a controlled manner, providing sustained release at the site of action and reducing the need for frequent dosing. One of the key advantages of Nano carriers in oral health is their ability to enhance the targeting of drugs to specific tissues. By functionalizing the surface of nanoparticles with targeting ligands, such as antibodies or peptides, it is possible to direct the drug specifically to diseased cells or tissues, minimizing the impact on healthy tissues and reducing side effects[12]. This targeted delivery is particularly valuable in the treatment of oral infections, periodontal disease, and oral cancer, where precise drug localization is crucial for therapeutic success. Nanoparticles can also be used to deliver a variety of therapeutic agents, including antibiotics, anti-inflammatory drugs, anticancer agents, and even

biomolecules such as genes or siRNA. The use of Nano carriers for combination therapies, where multiple drugs are delivered simultaneously, has also shown promise in improving treatment outcomes for complex oral health conditions. Despite their promising potential, the use of nanoparticles in oral health faces challenges, including issues related to stability, scaling up for commercial production, and regulatory approval. Moreover, safety concerns regarding the long-term effects of nanomaterials need to be addressed through rigorous research and testing. Nevertheless, the continued development of nanoparticles and Nano carriers holds great potential to revolutionize oral health treatments, offering more efficient, localized, and patient-friendly drug delivery systems.

Drug Delivery Systems in Periodontal Disease Management

Periodontal disease, one of the most common oral health conditions, requires effective drug delivery systems to address both the infection and inflammation associated with the disease. Traditional treatment methods, such as scaling and root planning, often fail to provide sufficient drug concentrations at the site of infection, especially in deep periodontal pockets. Consequently, there has been significant interest in the development of advanced drug delivery systems that can target periodontal tissues more effectively and deliver drugs directly to the affected area. One promising approach is the use of controlled-release systems, such as medicated gels, films, and inserts, which can be placed directly into periodontal pockets to provide sustained drug release over extended periods. These systems ensure that therapeutic concentrations are maintained at the site of infection, improving treatment outcomes and reducing the need for frequent reapplication. Nanotechnology has also shown promise in periodontal disease management[13]. Nano carriers, such as liposomes, solid lipid nanoparticles, and dendrimers, can encapsulate antimicrobial agents and anti-inflammatory drugs, ensuring localized drug delivery and enhanced therapeutic efficacy. These nanoparticles can penetrate the oral mucosa more effectively, allowing for better drug absorption and retention at the target site. Furthermore, the small size of nanoparticles enables them to reach areas that are difficult to access with traditional drug delivery methods, such as the deeper layers of the periodontal tissues. Another important advancement

systems for oral health has proven to be a pivotal breakthrough in the treatment and management of various oral diseases, offering solutions to many of the limitations faced by traditional drug administration methods. The complexity of the oral cavity, with its mucosal barriers, saliva, and variable permeability across different regions, has long posed challenges to achieving effective drug concentrations at the site of action. However, recent advancements in drug delivery technologies, including controlled-release systems, Nano carriers, and mucoadhesive formulations, have greatly improved the ability to target drugs directly to the affected oral tissues. These innovations not only enhance drug bioavailability and stability but also provide controlled and sustained drug release, reducing the need for frequent dosing and improving patient compliance. Nanotechnology, in particular, has revolutionized oral health drug delivery, offering significant advantages such as the ability to encapsulate both hydrophilic and hydrophobic drugs, protect them from degradation, and enhance their permeation across the mucosal barrier. Nano carriers, including liposomes, dendrimers, and solid lipid nanoparticles, can be engineered to target specific oral tissues, ensuring that therapeutic agents are delivered precisely to the site of infection, inflammation, or malignancy. Furthermore, these systems can be used to deliver a wide range of therapeutic agents, from antibiotics and anti-inflammatory drugs to gene therapies and anticancer agents, broadening the scope of oral health treatments. Mucoadhesive systems have emerged as another promising approach, as they prolong drug contact time with the mucosal surface, allowing for enhanced retention and more efficient drug absorption, especially in the treatment of chronic conditions like periodontal disease and oral ulcers. The integration of these advanced systems into clinical practice has the potential to significantly improve the management of oral infections, periodontal disease, microsites, and even oral cancer, where localized and sustained drug delivery is essential for effective therapy. Moreover, the development of combination therapies, which combine multiple therapeutic agents in a single delivery system, is paving the way for more comprehensive treatment options that can address multiple aspects of oral diseases simultaneously. Despite these exciting advancements, several challenges remain, including the need for standardized manufacturing processes, regulatory approval, and long-term safety assessments of novel drug delivery systems. Additionally, patient acceptance and ease of use are critical factors that must be addressed to ensure the widespread adoption of these technologies.

CONCLUSION

The development of advanced drug delivery

REFERENCES

1. Mortazavi, S. M., Sayed-Tabatabaei, L., Tabatabaei, M. S., & Moghaddam, A. V. (2024). Intraoral novel drug delivery systems. In *Intraoral Novel Drug Delivery Systems* (pp. 67–102).

2. Abdellatif, M. M., Ahmed, S. M., El-Nabarawi, M. A., & Teaima, M. (2023). Nano-delivery systems for enhancing oral bioavailability of drugs. *International Journal of Applied Pharmaceutics*, 13–19.
3. Lin, Z., & Kong, M. (2024). Investigation and application progress of oral drug delivery systems. *Biomedical Data Science*, 4, 51–58.
4. Sayed, O. M. (2024). Oral mucosal absorption: Mechanisms, methods, and challenges in drug delivery. *IJCMR*, 2, 155–170.
5. Alharbi, N. J., Aljohani, I. A. S., Al Rashdi, A. R., Al Shehri, H. M., Nashib, A. A., Madkhali, R. M., et al. (2022). Exploring recent progress in oral drug delivery systems. *SFS*.
6. Kneiszl, R., Hossain, S., & Larsson, P. (2021). In silico-based experiments on mechanistic interactions between several intestinal permeation enhancers with a lipid bilayer model. *Molecular Pharmaceutics*, 19, 124–137.
7. John, C., Vavre, N., Sawant, S., Sharma, A., Shah, K., & Patil, S. (2024). Oral mucoadhesive drug delivery system: Formulation strategies and evaluation techniques. *World Journal of Advanced Research and Reviews*, 24, 1706–1719.
8. Naghib, S. M., & Ahmadi, B. (2024). Micro- and nanoscale oral drugs delivery platforms. In *Micro- and Nanoscale Oral Drugs Delivery Platforms* (pp. 109–134). CRC Press.
9. Cahyani, D. M., Mubarak, A. S., Hariawan, B. S., Amalina, I., Drake, P., Parumasivam, T., et al. (2025). Nanoparticle tools for maximizing oral drug delivery. *Brazilian Journal of Medical and Biological Research*, 58, e14459.
10. Dolas, R. T., Kulkarni, A. D., Gulecha, V. S., Zalte, A. G., Talele, S. G., & Bedarkar, G. N. (2022). Buccal drug delivery system. *International Journal of Health Sciences*, 2996–3009.
11. Rao, T. R., Sravani, B., & Aarthi, R. (2025). Nanocarriers in drug delivery systems: An overview. *Journal of Advanced Scientific Research*, 16, 8–14.
12. Lin, Q., Zhang, L., & Zhang, Z. (2023). Oral delivery of nanoparticles: Challenges and opportunities. In *Oral Delivery of Nanoparticles* (pp. 591–598).
13. Dastidar, D. G., Ash, A., Saha, D., Chakraborty, P., & Tribedi, P. (2022). Periodontal film: A potential treatment strategy for periodontitis. *Drug Delivery Letters*, 12, 184–195.

Cite this article:

Dr. Balasiddharth S. Modern Approaches to Oral Drug Delivery: Modern Approaches to Oral Drug Delivery: Mucoadhesive, Bioadhesive, And Nanocarrier-Based Systems. *American Journal of Oral Medicine and Radiology*, 13(1), 2026, 10-18.



Attribution-NonCommercial-NoDerivatives 4.0 International