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REVOLUTIONIZING MEDICINE: THE FUTURE BUCCAL FILM-BASED DRUG DELIVERY SYSTEM

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Keywords:

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ABSTRACT: This study explores buccal drug delivery as an alternative to traditional oral medications, emphasizing its advantages in bioavailability, drug stability, and therapeutic efficacy. Key formulation factors, including swelling index, drug content, folding endurance, and surface pH, are evaluated alongside various production techniques such as solvent casting, hot-melt extrusion, and freeze-drying. The study also examines emerging technologies like co-crystallization, lipid-based formulations, solid dispersion technology, 3D printing, and AI-driven formulation design, which enhance drug stability and solubility. Findings indicate that buccal films improve bioavailability by bypassing first-pass metabolism while advanced formulation techniques enhance the solubility of poorly soluble drugs. However, challenges such as formulation stability and drug load capacity necessitate further research into nanotechnology, smart polymers, and multilayer films to optimize controlled drug release and permeability. Buccal films offer a promising drug delivery platform for various therapeutic applications, including cancer treatment, cardiovascular diseases, smoking cessation, hormone therapy, and pain management. Future advancements in smart materials and nanotechnology can further enhance therapeutic outcomes, patient compliance, and drug delivery efficiency, positioning buccal films as a transformative approach in modern medicine.

INTRODUCTION: The pharmacoeconomic advantages, treatment benefits, and patient convenience of oral medication delivery make it a popular choice [1]. Despite their immediate drug availability, oral preparations are constrained by problems with stability in aqueous conditions [2, 3]. Oral suspensions, which are appropriate for poorly soluble medications such as pediatric antibiotics and antacids, provide better stability but have drawbacks including particle aggregation [4, 5].

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Emulsions improve the solubility of lipophilic drugs, but they can also cause phase separation and creaming [6]. Drug solubility and penetration are improved by buccal drug delivery, which makes use of systems like liposomes and nanoparticles [7].

Buccal formulations, such as tablets, films, gels, patches, and sophisticated systems like microspheres and nanoparticles, offer enhanced bioavailability, controlled release, and prolonged mucosal contact, which makes them perfect for systemic or localized drug delivery [8-11]. A sophisticated drug delivery method called buccal films is intended to move pharmaceuticals through the buccal mucosa as shown in **Fig. 1.** These thin, flexible, and bioadhesive films allow for direct medication absorption into the systemic circulation

through the highly vascularized buccal mucosa, providing a non-invasive substitute for conventional oral administration. By avoiding the gastrointestinal system and the liver's first-pass metabolism, this technique increases bioavailability and facilitates quicker therapeutic effects.

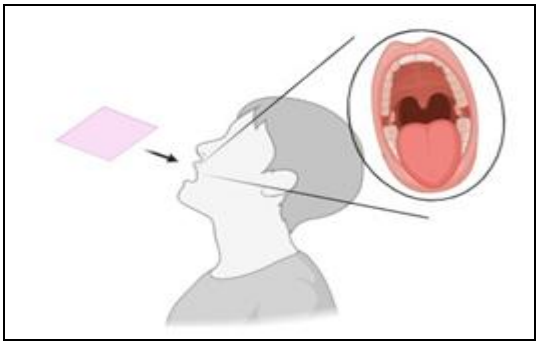

FIG. 1: STRUCTURE OF BUCCAL FILM ADMINISTRATION

Furthermore, buccal films shield the active pharmaceutical ingredients (APIs) from the harsh GI tract environment, improving their stability and effectiveness [12].

This oral drug delivery approach enhances treatment effectiveness by enabling controlled drug release and prolonged mucosal contact. It reduces the frequency of administration, minimizes side effects by localizing APIs at the site of action, and improves patient compliance.

Buccal films are particularly beneficial for individuals with dysphagia, children, and the elderly, as they are painless, easy to use, and eliminate the need for swallowing or water, making them a highly patient-friendly option [13].

TABLE 1: DIFFERENT FORMULATION OF BUCCAL DRUG DELIVERY

Sr. no.	Dosage form	Conclusion	Reference
1	Liposomes	A potential patient-friendly dose form, slower release, and increased stability during storage were all made achievable by the incorporation of VB6-loaded liposomes into buccal mucoadhesive film.	14
2	Solid Lipid Nanoparticles (SLNs)	These are found in nanoparticles and thin polymeric films. It has the potential to be developed into an effective mucoadhesive film formulation with a medication that is poorly soluble in water, according to the results.	15
3	Chitosan	The produced chitosan nanocomposite films with PLGA nanospheres embedded delivery system, according to the study's findings, have the potential to address the low bioavailability problem associated with EFF-Cg and, as a result, are suggested as a delivery method for the treatment of herpes infection.	16
4	Niosomes	In order to use the many biological qualities of propolis in a controlled-release medication delivery system, a new generation of oromuco-adhesive films incorporating niosomal propolis was introduced. For an extended length of time, the active component remained in the oral cavity.	17

Physiology: Buccal Films in Drug Delivery: Cheeks, lips, hard and soft palates, and tongue all contribute to the oral cavity's formation. The organization of epithelial structures distinguishes the oral mucosa, skin, and GI tract lining. The GI tract has a single-layered simple epithelium, whereas the skin and mouth cavity are made up of several cell layers with varied degrees of differentiation.

The masticatory mucosa in the oral cavity is distinguished by a keratinized epithelium that protects high-stress areas like the gingiva and hard palate. This structure has four unique layers: keratinized, granular, prickle-cell, and basal as shown in **Fig. 2.** In contrast, the lining mucosa, which maintains flexibility and elasticity, is made up of non-keratinized surface epithelium.

It covers regions such as the lips, cheeks, floor of the mouth, and soft palate and can be further classified into superficial, intermediate, prickle-cell, and basal layers.

The third type, called specialized mucosa, is exclusively found on the tongue's dorsal surface. It consists of both keratinized and non-keratinized epithelial layers. Water, lipids, and proteins can be found in intercellular spaces in all forms of mucosa, which contribute to their functional qualities [18].

These are potential retention sites for bioadhesive systems, including mucoadhesive drug delivery. There are several ways to administer drugs: buccal, oral, vaginal, rectal, nasal, and ocular [19].

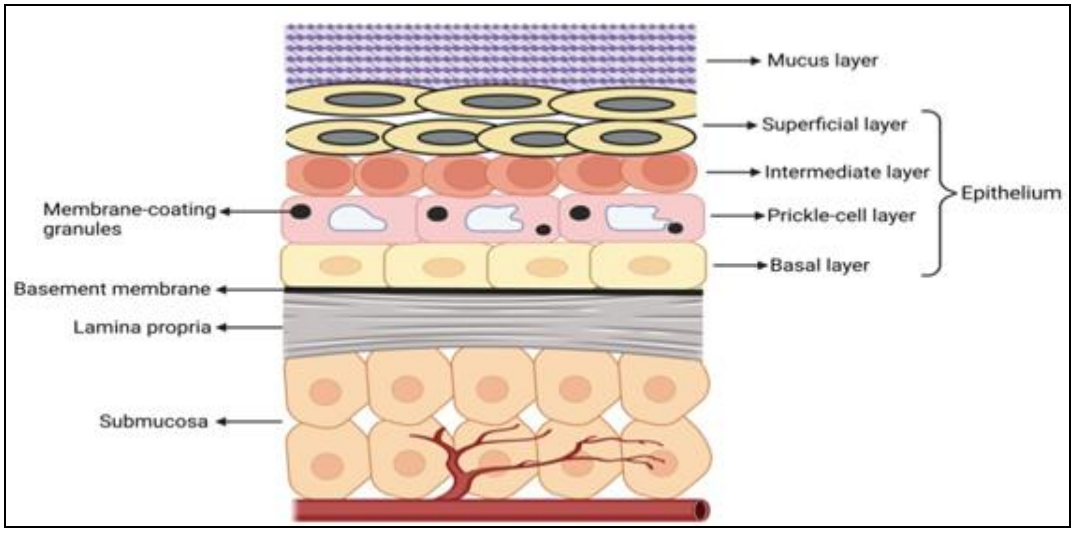

FIG. 2: STRUCTURE OF MUCOSA

Mechanism of Mucosal Adhesion in Oral Administration: The process of adhering several macromolecules to the surface of a mucous membrane. Membrane is still not well understood. To achieve a good contact, mucoadhesive must spread over the substrate, enhance the contact surface, and promote the diffusion of macromolecular chains within the mucus membrane.

To achieve good bioadhesion, attraction forces must outweigh repulsion forces while both are present during adhesion. The dose form and manner of administration can facilitate bioadhesion at each stage. A partially hydrated polymer may be absorbed by the substrate due to its attraction to surface water [20].

Drug Selection Criteria for Buccal Film:

Solubility: Effective drug release and absorption require optimal solubility in saliva. Techniques for improving solubility, such complexation or the use of co-solvents, are necessary for drugs with low solubility [21].

Stability: Because the buccal environment has a pH range of 5.5 to 7.4, the medicine of choice needs to be stable there. Drugs that are enzymatically unstable or breakdown in this pH range are not appropriate for buccal administration [22].

Irritation Potential: The buccal mucosa cannot be irritated or poisoned by drugs. Patient compliance may be jeopardized by medications that cause severe irritation [22].

Dose Requirements: For buccal films, medications with modest dosage requirements typically less than 30 mg are favored in order to guarantee consistent drug loading and patient comfort. Adhesion may be impacted and film size increased by drugs that require greater dosages [23].

Advantages and Challenges:

Improved Bioavailability: Buccal films allow medications to be absorbed directly through the buccal mucosa, avoiding the gastrointestinal tract and first-pass metabolism in the liver. This dramatically boosts bioavailability, especially for medications having low oral bioavailability, like peptides and proteins [24, 25].

Rapid Onset of Action: Because of the highly vascularized structure of the buccal mucosa, buccal films allow rapid drug absorption, resulting in a faster beginning of action than oral dose forms [26]. This function is especially useful in cases that require immediate therapeutic effects, such as angina or migraine episodes [27, 28].

Controlled and Sustained Release: The use of mucoadhesive polymers permits buccal films to provide longer and regulated drug release, reducing dose frequency and enhancing patient compliance with chronic therapy [29, 30].

Improved Patient Compliance: Buccal films are thin, lightweight, and simple to apply, making them more appealing to patients, particularly youngsters and the elderly who have difficulties swallowing standard oral formulations [31].

Targeted Local Delivery: Buccal films are particularly helpful for local treatment of oral disorders, such as infections, ulcers, and malignancies, since they administer medications directly to the site of action with limited systemic absorption, decreasing adverse effects [32].

Versatile Formulations: These films can be tailored to transport a wide range of drug types, including small molecules, peptides, and nanoparticles, allowing for their use in many therapeutic areas [33].

Limitations of Buccal Films:

Limited Drug Loading Capacity: Because of their small size and thin structure, buccal films have a limited drug-loading capacity, which can limit their usage for medications needing significant dosages [34].

Dependence on Salivary Flow, Buccal films require enough salivary flow for adhesion and breakdown. Patients with dry mouth (xerostomia) or impaired salivary production may have decreased medication absorption and therapeutic efficacy [35].

Potential for Mucosal Irritation: Prolonged contact with some medications or excipients in buccal films might produce irritation or discomfort, reducing patient compliance [36].

Complex Manufacturing Requirements: Buccal film production involves careful control over film thickness, medication homogeneity, and mucoadhesive characteristics, which can raise manufacturing costs and complexity.

Because of its hygroscopic nature, it needs to be stored in dry environments. Additionally, it exhibits the effervescent, fragile granule feature. For the stability and safety of the items, they need to be packaged specifically [37].

Different Methods for Buccal Film Preparation: Buccal film preparation involves a variety of processes that are adapted to individual needs such as drug loading, release profiles, and mechanical qualities. These methods aim to achieve optimal medication delivery through the buccal mucosa while maintaining film integrity and patient compliance. The most generally used methods for buccal film manufacturing are outlined below, with an emphasis on their benefits, limits, and applications.

Solvent Casting Method: It involves dissolving polymers in which water-soluble in water and adding the medicament. After dissolving the excipients in an appropriate solvent, the solutions are combined and agitated before being cast into a Petri plate as shown in **Fig. 3** and dried [38]. Advantages: Low Cost and Scalability: For both laboratory-scale and industrial-scale production, it is inexpensive and readily scalable [39]. Limitation: Equipment and Energy Demand: Thus far, achieving dosage homogeneity within manufactured films has proven to be challenging [40].

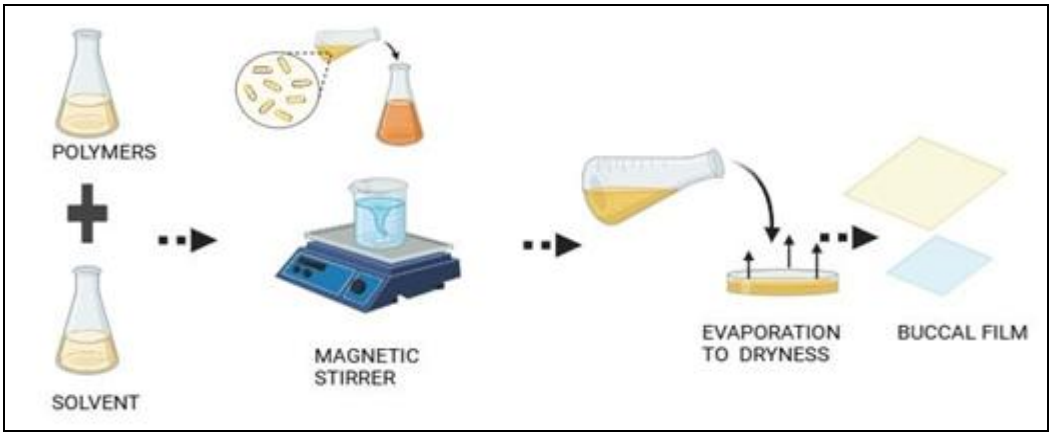

FIG. 3: SOLVENT CASTING

Hot-Melt Extrusion (HME): HME includes heating the polymer and drug mixture until it reaches a molten state, and then shaping it into films using an extruder [41].

Advantages: Avoids the need of solvents, produces faster, and is compatible with thermally stable pharmaceuticals [42].

Limitations: Not appropriate for thermolabile medicines and necessitates specialized equipment [43].

Semisolid Casting: The process employs the grain refining properties of the nanoparticles in the MMNC to create a slurry with the required globular structure for semi-solid casting [44].

Rolling Method: This process involves pre-mixing the film with additives, followed by adding the medication [45].

Advantages: Include high throughput, minimal material waste, and adaptability for large-scale manufacturing [46].

Limitation: High Capital Investment: Smaller producers might not be able to afford the significant infrastructure and equipment investments needed to establish and sustain rolling mills [47, 48].

Spray Drying: It is a method for quickly drying a liquid solution or suspension into a dry powder using a hot gas. The liquid is atomized into fine droplets using a nozzle or atomizer, which are then subjected to a stream of hot air, causing the solvent to evaporate and leaving behind dry particles. It is commonly used in pharmaceuticals for creating powders, granules, or films as shown in **Fig. 4** with regulated qualities, such as particle size, porosity, and stability [49, 50].

Advantage: Appropriate for Thermolabile Substances because spray drying only requires a brief exposure to high temperatures, it is an excellent method for materials that are sensitive to heat. Active pharmaceutical ingredients (APIs) or biologics like enzymes and vaccines are protected from thermal deterioration by the drying chamber's quick solvent evaporation [51].

Limitation: High Energy

Consumption: The energy intensity of spray drying is one of its main disadvantages. Significant thermal energy is needed for the drying process, which can raise operating expenses, particularly when working with materials that are sensitive to heat [52].

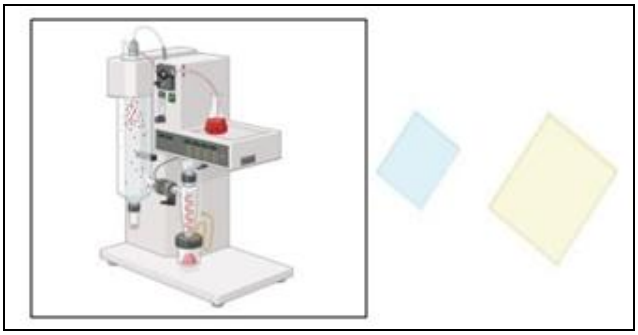

FIG. 4: SPRAY DRYING

Electrospinning: It is a process for creating nanofibers by applying a high-voltage electric field to a polymer solution or melt. The polymer solution is ejected through a nozzle, and the electric field elongates and dries it, resulting in ultra-thin strands. These strands are gathered on a solid surface to create a non-woven mat. This approach is frequently employed in medication administration, wound dressing, and tissue engineering due to the high surface area-to-volume ratio of the nanofibers [53]. The solid fibers are deposited once the solvent evaporates [54].

Advantage: Electro spinning creates nanofibers with high surface area-to-volume ratio, which improves drug solubility and bioavailability, especially for water-soluble medicines [55].

Limitation: restricted throughput, the sluggish nature of electrospinning restricts its capacity to quickly create huge amounts of nanofibers. Particularly in high-volume industries like textiles and filtration, its scalability for industrial applications is limited by its low production rate [56].

Limitation: Safety Issues Because of the Elevated Voltage, Operator safety is at risk due to the demand for high-voltage electric fields. Specialized equipment and strict safety regulations are

required, which raises operating complexity and expenses [57].

3D Printing: It is also known as additive manufacturing, is a cutting-edge production technology that builds three-dimensional items layer by layer using a computer design as shown in **Fig. 5.** For buccal films, 3D printing allows for precision deposition of polymers and active pharmacological components, resulting in films with specific drug loading, thickness, and release profiles. This technique enables the manufacture of tailored dosage forms with improved precision, reproducibility, and flexibility, making it perfect for customized drug delivery systems [58].

Advantage: Improved Innovation in Products, 3D printing encourages creativity and innovation by eliminating the limitations of traditional manufacturing, enabling designers to test out new concepts and ideas without taking on a large financial risk [59].

Limitation: High Starting Expenses, Purchasing sophisticated 3D printers and the related supplies might be unaffordable. Furthermore, energy and maintenance expenses raise the total cost, which reduces its viability for small-scale businesses [60].

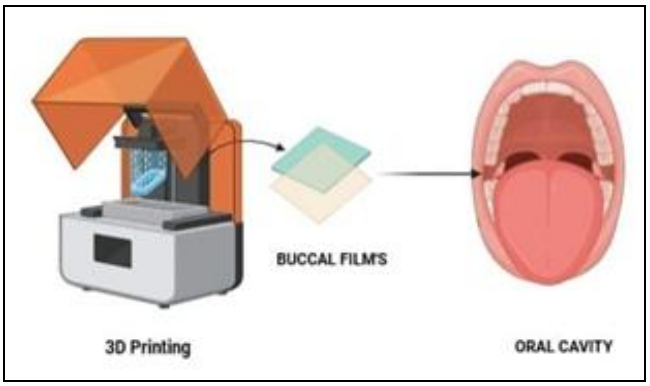

FIG. 5: 3D PRINTING

Freeze-Drying (Lyophilization): Freeze-drying, also known as lyophilization, is a dehydration technique that removes water from temperature-sensitive compounds through sublimation at low temperatures and pressures. Freeze-drying buccal films entails freezing a polymer-drug solution or suspension and then lowering the surrounding pressure, allowing frozen water to sublimate directly from solid to gas. This approach produces porous films that promote rapid drug dissolution and absorption, which makes it ideal for buccal drug delivery applications [61].

Advantages:

Drug Stability Retention: The low-temperature technique makes it suitable for thermo labile pharmaceuticals [62].

Improved Storage Stability: Creates dry films with a longer shelf life [63].

Limitation: Possibility of Remaining Wetness, It can be challenging to completely remove moisture during the secondary drying stage, leaving the product with some moisture remaining. This may have an impact on the freeze-dried material's stability and shelf life [64].

Evaluation Parameters of Buccal Film:

Measurement of Surface pH: After placing the electrode on the swelling film's surface and letting it equilibrate for a minute, the surface pH was measured as shown in **Fig. 6.** After removing the films, the pH was determined by applying a pH meter's mixed glass electrode (Universal Enterprises, India) to the wet film's surface. The three observations' mean was determined [65, 66]. As the number of polymers in the formulations increases, the films thickness will also increase. They were chosen for additional examination since they had the thickest films and were free of tears. A computerized Vernier caliper is used to measure thickness at three separate points [67, 68].

FIG. 6: MEASUREMENT OF SURFACE pH

Folding Stamina: The film's folding endurance was assessed by folding a single patch repeatedly in the same spot until it broke or folded by hand, which was deemed adequate to demonstrate the film's good qualities. The value of folding endurance is determined by how many times the

film could be folded in the same spot without breaking [69, 70].

Drug Content: Each Buccal film, with a surface area of 1 cm^2, was cut from various locations, submerged in a methanol-water solvent mixture as shown in **Fig. 7,** and swirled for 6 hours in a water bath that is thermostatically controlled (37±1 ◦C) [71].

FIG. 7: DRUG CONTENT

Index of Swelling: To ascertain the capacity of hydrophilic polymers utilized in formulation to absorb water following hydration, the swelling index is measured.

According to reports, the polymer's hydration and swelling behavior are essential to its bioadhesive properties since they allow the film to make close contact with the mucosal surface [72]. Additionally, it will be noted that films made of the hydrophilic polymers broke down quickly [73].

$$SI \text{ is equal to } (W_2\text{-}W_1) / W_1 \times 100$$

Where, W_1 is the patch's initial weight, W_2 is its final weight [74].

Current Innovations in Buccal Film Technology: Formulation scientists are always looking for new ways to improve the stability, solubility, and therapeutic effectiveness of medications. Co-crystallization techniques, lipid-based formulations, and solid dispersion technology have all shown promise in enhancing the bioavailability of poorly soluble medications. Furthermore, the medication development process is being revolutionized by the use of 3D printing technology for customized dosage forms and the incorporation of artificial intelligence (AI) in formulation design, which results in quicker and more effective formulations. In order to overcome issues with medication solubility, stability, and bioavailability, formulation techniques have changed. Drug dissolution rates and bioavailability are improved by solid dispersion technology, which uses carriers like polymers or surfactants, especially for poorly soluble substances. Lipid-based formulations offer benefits in both oral and parenteral administration by enhancing medication solubility and absorption through lipidic matrix or vesicles. A non-dissolving thin matrix modified release dosage form made up of one or more polymer films or layers is called buccal film [75].

A thin, non-dissolving matrix intended for modified-release dose forms is called a buccal film. The medicine and/or additional excipients are contained in one or more polymer layers. To enable the regulated release of the medication, these films may have a mucoadhesive polymer layer that sticks to the teeth, gingiva, or oral mucosa. Either the oral cavity (unidirectional release), the oral mucosa (unidirectional release), or both (bidirectional release) may receive this release. After a set amount of time, the film is taken out of the mouth and thrown away [76]. Generally speaking, oral consumption is the recommended method of medicine administration because of its high patient compliance. In comparison to parenteral dose forms, oral dosage forms are also more affordable. Large molecular size, high molecular mass, physicochemical instability, enzymatic degradation, and low membrane permeability are some of the obstacles that make developing oral formulations for protein therapeutics extremely difficult. As a result, only a small percentage of protein medications are offered orally; the majority are available in parenteral formulations. Notwithstanding these obstacles, significant work and a variety of strategies have been used to create oral dosage forms for protein medications, leading to notable advancements in recent years. Oral protein delivery systems have advanced significantly as a result of nanotechnology improvements; some of these developments are detailed in the sections that follow [77].

The interaction between nanoparticles and the formulation base must be carefully considered for effective sublingual or buccal pharmaceutical administration. Pharmaceutical formulations depend heavily on the stability of the nanoparticles, especially during production and storage. Increasing the formulation's residence duration in the buccal or sublingual region will help with systemic absorption and pharmaceutical permeability.

Results of how formulations containing nanoparticles interact with mucosal tissue vary. The majority of research demonstrates that the drug is released continuously from nanoparticles in dosage forms, where it diffuses into the formulation base and is absorbed by the mucosa [78].

TABLE 2: BUCCAL DRUG DELIVERY STIDIES REPORTED

Auther(S)	Year	Formulation	Study Focus	Limitation
Han *et al.*	1999	Mucoadhesive buccal disks with nalbuphine prodrug	Investigated drug release kinetics and mucoadhesive properties under varying formulation variables.	Limited to *in-vitro* studies; no *in-vivo* evaluation for therapeutic efficacy.
Varshosaz & Dehghan	2002	Buccoadhesive tablets with nifedipine	Developed buccal tablets with enhanced drug bioavailability and sustained release.	Did not address patient compliance or long-term safety concerns.
Labot *et al.*	2002	Double-layered mucoadhesive tablets with nystatin	Formulated antifungal tablets for local delivery to treat oral candidiasis.	Limited clinical data on efficacy; formulation stability over time not explored.
Yong *et al.*	2001	Buccal adhesive tablets with omeprazole	Evaluated physicochemical properties for stabilizing acid-labile drugs in a buccal formulation.	Stability under varying pH conditions in the oral cavity was not studied extensively.
Dortunc *et al.*	1998	Buccoadhesive tablets with pindolol	Developed and tested mucoadhesive tablets for systemic delivery of a beta-blocker.	Did not investigate patient acceptance or ease of administration.

Evolving Role in Medicine: Applications in Targeted Therapy:

Pain Management: first-line treatment for chronic pain in suitable patients who have been identified by risk/benefit studies [79].

Cardiovascular Treatment: Nitro-glycerine-loaded buccal films are widely used in angina treatment, offering rapid absorption for quick relief from chest pain. This delivery system ensures that the drug acts fast without the delays caused by oral ingestion [80].

Smoking Cessation: Nicotine-loaded buccal films have emerged as an alternative to nicotine gums or patches for smoking cessation. These films deliver nicotine quickly to reduce cravings and withdrawal symptoms, enhancing patient adherence [81, 82].

Hormonal Replacement Therapy: Estradiol-loaded buccal films provide a controlled release of the hormone, offering an effective alternative to oral tablets for hormone replacement therapy in menopausal women [83].

Anti-emetic Therapy: Ondansetron-loaded buccal films offer targeted treatment for nausea and vomiting, particularly in chemotherapy patients. These films provide fast relief by ensuring rapid absorption of the drug [84, 85].

Pediatric Applications: In pediatric care, buccal films such as those containing ibuprofen provide a non-invasive, easy-to-administer alternative for treating fever and pain in children [86, 87].

Cancer Therapy: The use of buccal films for targeted delivery of chemotherapeutic drugs like 5-fluorouracil is an exciting area of research. These films allow for localized treatment of oral malignancies or other cancers in the upper digestive tract, decreasing the systemic toxicity associated with chemotherapy [88].

Biologics and Peptide Delivery: Buccal films could be used to deliver biologics such monoclonal antibodies and peptide-based medicines. This method may enhance the bioavailability of large, complex compounds, which are generally destroyed in the gastrointestinal tract [89].

Immunotherapy: Buccal films could be utilized for mucosal immunization, providing a non-invasive method of administering vaccines. This technique may improve the immune response both locally and systemically, which is especially important for respiratory and gastrointestinal diseases [90].

Diabetes Management: The distribution of GLP-1 receptor agonists, such as liraglutide, via buccal films offers a viable alternative for diabetes control. These films can give prolonged release of the medicine, enhancing patient compliance and removing the need for regular injections [91, 92].

Neurological Disorders: For disorders like Parkinson's disease, buccal films can deliver dopamine precursors or other drugs in a controlled release manner, improving symptom management with less adverse effects [93].

Future Trends and Innovations:

Nanotechnology Integration: The inclusion of nanocarriers into buccal films is gaining popularity. These nanocarriers improve drug stability, promote mucosal permeability, and allow for the delivery of complex compounds like peptides and proteins [94, 95].

3D Printing of Buccal Films: Advances in 3D printing technology have created new possibilities for the individualized manufacturing of buccal films. This provides exact control over medicine dosage, film thickness, and release patterns, adapting to particular patient demands [96, 97].

Application of Smart Polymers: Smart polymers, which respond to stimuli such as pH, temperature, and ionic strength, are being studied. These polymers improve mucoadhesion and enable on-demand medication release, providing more control and efficiency [98].

Targeted Gene and Protein Delivery: Buccal films are being created for the non-invasive delivery of gene treatments, vaccinations, and monoclonal antibodies. Advances in encapsulation methods and permeation enhancers make this a practical approach to treating systemic illnesses [99].

Multilayer Films for Complex Therapies: Multilayer buccal films are developing as a promising platform for multimodal medication administration, either sequentially or simultaneously. This is particularly relevant for combination therapy in cancer and infectious disorders [100].

Integration of Artificial Intelligence (AI) in Formulation Design: AI and machine learning are used to optimize formulation parameters, anticipate drug release kinetics, and improve scalability of buccal film production [101].

CONCLUSION: Buccal films are a novel and patient-friendly drug delivery method that avoids first-pass metabolism and provides enhanced bioavailability, a quick beginning of action, and regulated drug release. They improve patient compliance because of their thin, flexible, and mucoadhesive qualities, which make them especially appropriate for people who have trouble swallowing. The use of nanotechnology, including niosomes, liposomes, chitosan, and solid lipid nanoparticles, enhances medication stability, retention, and therapeutic effectiveness. Advances in fabrication techniques, including as solvent casting, hot-melt extrusion, 3D printing, and electrospinning, continue to refine their formulation despite obstacles such as restricted drug-loading capacity, reliance on salivary flow, and complex manufacturing requirements. Buccal films are a strong substitute for traditional oral dose forms because they have the potential to deliver drugs effectively, locally, and systemically, especially when loaded with nanoparticles. With its higher bioavailability, regulated drug release, and increased patient compliance, buccal film technology has developed into a potential drug delivery method. Innovations like 3D printing, smart polymers, AI-driven formulation design, and the integration of nanotechnology are revolutionizing the industry and making it possible to distribute tiny drugs, biologics, and gene therapies effectively.

The adaptability of buccal films in contemporary medicine is demonstrated by their use in diabetes management, cancer treatment, cardiovascular disease, and pain management. Buccal films have the potential to become an essential platform for targeted and customized drug administration, transforming therapeutic methods across a range of medical specialties as research continues to improve mucosal permeability and address formulation issues.

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