International Journal of Pharmaceutical Sciences and Drug Analysis

E-ISSN: 2788-9254
P-ISSN: 2788-9246
IJPSDA 2024; 4(1): 72-79
www.pharmacyjournal.info
Received: 02-02-2024
Accepted: 15-03-2024

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Floating towards enhanced drug delivery: The promise of intragastric floating systems

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Abstract
Intragastric Floating Drug Delivery Systems represent a cutting-edge advancement in pharmacology, revolutionizing drug delivery by enhancing the gastric retention and bioavailability of medications. By capitalizing on buoyancy principles, Floating Drug Delivery Systems ensures prolonged drug release and improved absorption, particularly for drugs absorbed in the stomach or upper small intestine. This is achieved through the incorporation of effervescent components and low-density polymers, which enable Floating Drug Delivery Systems to float on gastric fluids, thereby maintaining optimal drug presence in the stomach for therapeutic effects. It can be classified into single-unit and multiple-unit systems, each offering unique advantages. Single-unit systems, such as hydrodynamically balanced systems and gas-generating systems, provide reduced dosing frequency and targeted drug delivery. On the other hand, multiple-unit systems, including floating beads and microspheres, offer benefits such as reduced risk of dose dumping and more uniform distribution throughout the stomach. Despite challenges related to maintaining appropriate buoyancy and formulation stability, Floating Drug Delivery Systems holds great promise for the treatment of various conditions, including peptic ulcers, gastroesophageal reflux disease, and Parkinson's disease. Additionally, Floating Drug Delivery Systems is well-suited for controlled drug release, offering a means to maintain therapeutic levels over an extended period, thereby minimizing side effects. Ongoing research endeavors are dedicated to optimizing Floating Drug Delivery Systems, with the ultimate goal of enhancing patient outcomes and advancing drug delivery technology. Through continuous refinement and innovation, Floating Drug Delivery Systems emerges as a valuable tool in modern pharmacotherapy, offering innovative solutions to improve medication efficacy and enhance patient quality of life.

Keywords: Floating drug delivery systems, buoyancy, hydrodynamically balanced systems

1. Introduction
Intragastric Floating Drug Delivery Systems (FDDS) represent a cutting-edge approach in pharmacology designed to enhance the gastric retention time of medications, thereby optimizing their bioavailability and therapeutic efficacy [1]. These innovative systems leverage buoyancy to ensure that drugs remain afloat on gastric fluids, providing sustained release and improved absorption, particularly for drugs absorbed primarily in the stomach or upper small intestine. The human gastrointestinal (GI) tract presents significant challenges for drug delivery due to its complex motility patterns and varying pH levels, which can affect how long a drug stays in the stomach and where it is absorbed [2]. Traditional oral drug delivery systems often fail to address these issues effectively, leading to suboptimal drug bioavailability and necessitating frequent dosing to maintain therapeutic levels. FDDS offers a solution to these challenges by maintaining the drug in the stomach for an extended period. The effectiveness of FDDS is based on the principle of buoyancy [3]. These systems are designed to float on the gastric fluids due to their lower density compared to the fluid in the stomach. This floating capability is typically achieved through the incorporation of specific components in the formulation. Effervescent components, such as sodium bicarbonate, citric acid, or tartaric acid, are common [4]. These substances react with gastric acid to produce carbon dioxide gas, which becomes entrapped within the gel matrix of the system, causing it to float. Another approach involves using low-density polymers, such as hydroxypropyl methylcellulose (HPMC), ethyl cellulose, and certain hydrogels, which form a matrix that remains buoyant on gastric fluids. These materials can swell upon contact with gastric fluids, decreasing the overall density and ensuring buoyancy [5].
FDDS can be broadly classified into single-unit and multiple-unit systems, each with distinct characteristics and applications. Single-unit systems include floating tablets or capsules that either swell or produce gas upon contact with gastric fluids, ensuring that they remain buoyant [6].

Examples of single-unit systems include hydrodynamically balanced systems (HBS), which are formulated with polymers that swell and form a gel-like structure in the stomach, maintaining buoyancy, and gas-generating systems, which contain effervescent compounds that release carbon dioxide, creating a floating mass. Multiple-unit systems consist of smaller, discrete units like beads, granules, or microspheres that float individually [7]. This design offers advantages such as reduced risk of dose dumping and more uniform distribution throughout the stomach. Examples of multiple-unit systems include floating beads made from materials like alginate, which encapsulate the drug and maintain buoyancy due to their inherent low density, and microspheres, which are small, spherical particles that float on gastric fluids, providing a sustained release of the drug [8]. The primary advantages of FDDS include prolonged gastric retention, enhanced bioavailability, reduced dosing frequency, and targeted drug delivery. By floating on gastric fluids, FDDS can remain in the stomach for an extended period, allowing for continuous drug release and absorption. This is particularly beneficial for drugs that are absorbed in the stomach or the upper intestine, as the prolonged presence leads to improved bioavailability and more consistent therapeutic effects [9]. Additionally, sustained release formulations provided by FDDS can reduce the need for frequent dosing, improving patient compliance and convenience. Targeted drug delivery is another significant advantage, as FDDS can provide targeted delivery to specific regions within the stomach, which is particularly beneficial for localized therapies, such as treatments for gastric ulcers [10].

Despite these benefits, several challenges and considerations must be addressed in the development and use of FDDS. Maintaining appropriate density and buoyancy is crucial, as the system must have a lower density than gastric fluids to ensure floating. Variations in gastric conditions, such as pH and fluid volume, can affect buoyancy. Gastric motility is another factor that can influence the effectiveness of FDDS, as factors like gastric emptying time and motility patterns vary among individuals [11]. Formulation stability is also essential, as ensuring the stability of the floating system during storage and throughout its residence in the stomach is crucial for maintaining its effectiveness. Additionally, individual differences in gastric physiology, such as variations in pH and fluid composition, can impact the performance of FDDS. It has a wide range of applications, particularly for drugs that benefit from extended gastric retention [12]. Some notable applications include treatments for peptic ulcers, where drugs like antacids or antibiotics used to eradicate Helicobacter pylori can benefit from prolonged gastric retention, enhancing their therapeutic efficacy. FDDS can also be used in the treatment of gastroesophageal reflux disease (GERD), providing sustained release of drugs that reduce acid secretion and offering better management of GERD symptoms. In the case of Parkinson's disease, medications such as levodopa, which are absorbed in the upper gastrointestinal tract, can have enhanced bioavailability with FDDS, leading to improved symptom control [13]. FDDS can also be used for controlled drug release, providing a controlled release profile to maintain therapeutic levels over an extended period, reducing the need for frequent dosing and minimizing side effects.

As research and technological advancements continue to optimize these systems, FDDS promises to improve patient outcomes and advance drug delivery technology, making it an invaluable tool in modern pharmacotherapy. By ensuring prolonged gastric retention, FDDS enhances the bioavailability and therapeutic efficacy of drugs that benefit from extended presence in the stomach [14]. Despite the challenges associated with their formulation and variability in gastric conditions, ongoing research and technological advancements continue to optimize FDDS. This evolving understanding and development of FDDS are poised to play a crucial role in improving patient outcomes and advancing the field of drug delivery, making it an invaluable tool in modern pharmacotherapy. The future of FDDS looks promising as it continues to offer innovative solutions to longstanding challenges in drug delivery, ultimately enhancing the quality of life for patients requiring sustained medication therapy.

2. Mechanism of Action

The FDDS is based on the principle of buoyancy. When the delivery system is ingested, it floats on the gastric fluids due to its lower density compared to the fluids.

2.1 Effervescent Components: Effervescent components are a crucial aspect of Intragastric Floating Drug Delivery Systems (FDDS) because they facilitate buoyancy through the generation of carbon dioxide gas. When the drug delivery system, which contains these effervescent components, comes into contact with the gastric fluids in the stomach, a chemical reaction occurs that produces carbon dioxide gas [15]. This reaction is essential for creating the buoyant force necessary to keep the drug delivery system afloat in the gastric environment. The effervescent reaction typically involves an acid-base interaction. Commonly used acids include citric acid and tartaric acid, while bases such as sodium bicarbonate are also integral to this process [16]. When these components dissolve in the acidic environment of the stomach, the acid reacts with the bicarbonate, resulting in the formation of carbon dioxide gas. This reaction can be represented by the following equation:

Citric Acid + Sodium Bicarbonate → Sodium Citrate + Carbon Dioxide (CO_2) + Water

As the reaction proceeds, the carbon dioxide gas produced becomes entrapped within the matrix of the drug delivery system. This gas generation is crucial for reducing the overall density of the system. The presence of these gas bubbles within the delivery matrix decreases its density below that of the gastric fluids [17]. Consequently, the drug delivery system floats on the surface of the gastric fluids rather than sinking to the bottom of the stomach. The buoyancy induced by the effervescent reaction ensures that the delivery system remains in the stomach for an extended period. This prolonged gastric retention is beneficial for drugs that are primarily absorbed in the stomach or the upper part of the small intestine, as it provides a sustained release of the drug [18]. The extended presence of the drug in the stomach enhances its absorption window, leading to improved bioavailability and more consistent therapeutic effects. To ensure the effectiveness of the effervescent system, the formulation must be carefully controlled. The ratio of acid to base must be optimized to produce a sufficient amount of carbon dioxide without causing

excessive gas formation, which could lead to discomfort or bloating. Additionally, the physical properties of the delivery matrix, such as its porosity and the strength of its gel structure, must be engineered to retain the generated gas effectively while allowing the gradual release of the drug [19].

The use of effervescent components in FDDS is particularly advantageous because it provides immediate buoyancy. This can be especially important in cases where rapid onset of action is desired, as the drug can be released and begin absorption soon after administration. Furthermore, the gas-generating reaction can also help in the uniform distribution of the drug delivery system throughout the gastric contents, enhancing the uniformity of drug release [20]. However, there are challenges associated with the use of effervescent components in FDDS. One of the primary challenges is the potential variability in the rate of gas generation, which can affect the consistency of buoyancy and drug release. Factors such as the presence of food in the stomach, variations in gastric pH, and individual differences in gastric motility can all influence the performance of the effervescent system. Additionally, ensuring the stability of the effervescent components during storage and handling is crucial, as premature reaction or degradation can compromise the effectiveness of the drug delivery system [21].

2.2. Low-Density Polymers: Low-density polymers are essential components of Intragastric Floating Drug Delivery Systems (FDDS) as they contribute to the buoyancy of the delivery system. These polymers possess intrinsic properties that allow the FDDS to float on gastric fluids without the need for gas generation. The mechanism by which low-density polymers enable buoyancy involves several key steps [22]. First, the selection of polymers with inherently low density is critical. Examples of such polymers include hydroxypropyl methylcellulose (HPMC), ethyl cellulose, and various hydrogels. These polymers are chosen for their ability to swell upon contact with gastric fluids and absorb water, thereby increasing in volume while maintaining a low density. When the FDDS containing these polymers is ingested, it comes into contact with the gastric fluids in the stomach [23]. The polymers within the delivery system begin to absorb the fluid, leading to swelling. This swelling behavior causes the polymer matrix to expand, significantly reducing its overall density while maintaining its integrity. As the polymers swell and absorb gastric fluids, they form a gel-like structure that encloses the drug [24]. This gel matrix, filled with absorbed fluids, creates a buoyant system that floats on the surface of the gastric contents. The reduced density of the swollen polymer matrix allows the FDDS to remain buoyant for an extended period, ensuring prolonged gastric retention and sustained drug release [25].

One of the advantages of using low-density polymers in FDDS is their ability to provide consistent and prolonged floating without the need for gas generation. These polymers offer a reliable mechanism for achieving buoyancy and drug release characteristics, making them versatile for various therapeutic applications [26]. Additionally, the release rate of the drug from the polymer matrix can be controlled by modifying the polymer composition, thickness, and degree of cross-linking. This allows for tailored drug release profiles that meet the specific therapeutic needs of different medications. However, challenges associated with the use of low-density polymers in FDDS include ensuring the stability of the polymer matrix during storage and handling. Proper formulation and optimization of the polymer characteristics are necessary to maintain the integrity of the system and ensure effective drug release [27].

3. Types of FDDS

3.1. Single-Unit Systems: Intragastric Floating Drug Delivery Systems (FDDS) can be formulated as tablets or capsules that exhibit buoyancy upon contact with gastric fluids. Two common types of FDDS formulations include Hydrodynamically Balanced Systems (HBS) and Gas-Generating Systems. HBS utilize polymers that have the ability to swell in the stomach environment. When these polymers come into contact with gastric fluids, they absorb water and swell, creating a gel-like structure that maintains the system's buoyancy [28]. This swelling action ensures that the FDDS remains afloat on the gastric fluids for an extended period, allowing for sustained drug release and absorption. On the other hand, Gas-Generating Systems incorporate effervescent components such as sodium bicarbonate into the formulation. Upon ingestion and exposure to gastric fluids, these effervescent components react with the acidic environment of the stomach, producing carbon dioxide gas [29]. The generated gas becomes trapped within the FDDS, causing it to float on the surface of the gastric contents. This floating mass ensures prolonged gastric retention and sustained release of the drug encapsulated within the system. Both HBS and Gas-Generating Systems offer advantages in terms of ensuring buoyancy and facilitating controlled drug release. HBS formulations are advantageous for their simplicity and reliance on polymer swelling to achieve buoyancy, while Gas-Generating Systems provide immediate buoyancy through the rapid generation of gas upon contact with gastric fluids [30]. However, both formulations require careful consideration of factors such as the choice of polymers or effervescent components, as well as the formulation's stability and compatibility with the drug being delivered.

3.2. Multiple-Unit Systems: Intragastric Floating Drug Delivery Systems (FDDS) can also be designed as multiple-unit systems consisting of small, discrete units such as beads or granules that float individually. Two common types of multiple-unit systems include Floating Beads and Microspheres [31]. Floating Beads are spherical particles made of polymers like alginate. These beads are engineered to encapsulate the drug within their matrix while also possessing buoyant properties. When ingested, the Floating Beads come into contact with the gastric fluids, and their low-density polymer composition enables them to float on the surface of the gastric contents [32]. This buoyant behavior ensures that the Floating Beads remain in the stomach for an extended period, allowing for sustained drug release. The encapsulated drug is gradually released from the beads over time, contributing to prolonged drug absorption and enhanced therapeutic efficacy [33].

Microspheres are another type of multiple-unit system used in FDDS. These are small, spherical particles with diameters typically ranging from micrometers to millimeters. Microspheres are designed to float on gastric fluids due to their low density, which allows them to remain suspended in the stomach environment. Similar to Floating Beads,

Microspheres encapsulate the drug within their structure and provide sustained release upon contact with gastric fluids [34]. The small size of Microspheres offers advantages such as increased surface area for drug release and improved dispersion throughout the gastric contents, leading to more uniform drug absorption. Both Floating Beads and Microspheres offer several advantages in drug delivery. Their multiple-unit nature reduces the risk of dose dumping compared to single-unit systems, where the entire drug dose is released simultaneously [35]. Additionally, the individual units can disperse more evenly throughout the stomach, enhancing drug distribution and absorption. Furthermore, the buoyant properties of these systems prolong gastric retention, ensuring sustained drug release and improved bioavailability. However, challenges exist in the formulation and optimization of Floating Beads and Microspheres for FDDS [36]. Achieving uniform drug loading within each unit and controlling the release kinetics are critical considerations. Additionally, ensuring the stability of the units during storage and handling is essential to maintain their integrity and drug release characteristics.

Intragastric Floating Drug Delivery

Intragastric Floating Drug Delivery	Examples of Drugs	Mechanism of Action	Used in Treatment for	Advantages	Disadvantages	References
Hydrodynamically Balanced Systems (HBS)	Propranolol, Metformin	Swell in gastric fluid, forming a gel-like structure to maintain buoyancy	Peptic ulcers, GERD, Controlled drug release	Prolonged gastric retention, Enhanced bioavailability	Formulation stability challenges	[37]
Gas-Generating Systems	Ranitidine, Aspirin	Effervescent components react with gastric acid to produce CO_2, creating a floating mass	Peptic ulcers, GERD	Reduced dosing frequency, Targeted drug delivery	Variability in gastric conditions affecting buoyancy	[38]
Floating Beads	Diclofenac, Omeprazole	Made of low-density polymers like alginate, encapsulating drugs to maintain buoyancy	Peptic ulcers, Controlled drug release	Reduced risk of dose dumping, Uniform drug distribution	Limited drug payload, Difficulty in scaling up production	[39]
Microspheres	Levodopa, Theophylline	Small spherical particles with low density float on gastric fluids	Parkinson's disease, Asthma	Sustained drug release, Improved patient compliance	Risk of gastric irritation, Difficulty in formulation	[40]

4. Advantages

Intragastric Floating Drug Delivery Systems (FDDS) offer several distinct advantages that contribute to their effectiveness in drug delivery and therapeutic outcomes. These advantages encompass prolonged gastric retention, enhanced bioavailability, reduced dosing frequency, and targeted drug delivery, each playing a crucial role in improving patient care and treatment efficacy [41]. Prolonged gastric retention is a key feature of FDDS, ensuring that the drug delivery system remains in the stomach for an extended period. This prolonged residence time allows for continuous drug release, facilitating sustained therapeutic effects. By remaining buoyant on the gastric fluids, FDDS overcomes the challenge of rapid gastric emptying, which can limit the absorption of orally administered drugs [42]. Instead, the system floats on the surface of the gastric contents, gradually releasing the drug over an extended duration. This prolonged release profile not only improves drug absorption but also reduces the frequency of dosing, enhancing patient convenience and compliance.

Enhanced bioavailability is another significant advantage offered by FDDS. Drugs that are absorbed primarily in the stomach or the upper intestine benefit greatly from prolonged gastric retention, leading to improved bioavailability [43]. By extending the drug's exposure time to the absorption sites, FDDS maximizes the opportunity for efficient drug uptake into the bloodstream. This is particularly beneficial for drugs with low solubility or permeability, as well as those susceptible to degradation in the gastrointestinal tract. By optimizing bioavailability, FDDS enhances the therapeutic efficacy of drugs, ensuring that patients receive the intended therapeutic benefit from their medications [44]. Reduced dosing frequency is a practical advantage of FDDS that enhances patient compliance and treatment adherence. Sustained release formulations provided by FDDS can significantly reduce the need for frequent dosing, thereby simplifying the medication regimen for patients. Instead of multiple daily doses, patients may only need to take medication once or twice daily, leading to improved treatment adherence and better disease management outcomes. This is particularly advantageous for chronic conditions requiring long-term medication therapy, where maintaining consistent drug levels in the bloodstream is essential for effective symptom control and disease management [45].

Targeted drug delivery is a unique feature of FDDS that allows for localized therapy within the stomach. By providing targeted delivery to specific regions within the stomach, FDDS can optimize the therapeutic effect of drugs for conditions such as gastric ulcers or localized infections. For example, FDDS can be designed to release antimicrobial agents directly at the site of infection, minimizing systemic side effects and improving treatment efficacy. Additionally, targeted delivery within the stomach can enhance the bioavailability of certain drugs by ensuring direct contact with the absorption sites, further optimizing their therapeutic effects [46].

5. Challenges and Considerations

Intragastric Floating Drug Delivery Systems (FDDS) offer a promising approach to drug delivery, but their effectiveness is influenced by various factors that must be carefully considered during formulation and optimization. These factors include density and buoyancy, gastric motility, formulation stability, and patient variability, each playing a crucial role in the performance and reliability of FDDS [47]. Density and buoyancy are fundamental principles governing the behavior of FDDS within the gastrointestinal tract. For the system to float effectively on gastric fluids, it must maintain a lower density than the surrounding fluids. Achieving optimal buoyancy requires careful consideration of the formulation components and their interactions with gastric fluids. Any deviation from the desired density can compromise the buoyancy of the system, impacting its ability to remain afloat and prolong gastric retention [48]. Moreover, variations in gastric conditions, such as pH levels and fluid volume, can affect the buoyancy of FDDS. Changes in these factors may alter the density of the system or influence its interaction with gastric fluids, potentially leading to fluctuations in performance and drug release kinetics [49]. Gastric motility plays a critical role in the performance of FDDS by influencing factors such as gastric emptying time and motility patterns. The rate at which the stomach empties its contents into the small intestine can impact the duration of gastric retention and the extent of drug absorption [50]. Slow gastric emptying may prolong the residence time of FDDS in the stomach, enhancing drug release and absorption. Conversely, rapid gastric emptying may reduce the efficacy of FDDS by expelling the system from the stomach before complete drug release occurs. Additionally, variations in gastric motility patterns among individuals can affect the distribution and dispersion of FDDS within the stomach, further influencing drug release kinetics and absorption profiles [51].

Formulation stability is essential for ensuring the efficacy and reliability of FDDS throughout its residence in the gastrointestinal tract. The floating system must maintain its structural integrity and drug release characteristics during storage and upon exposure to gastric fluids. Formulation instability can result in premature drug release, inconsistent floating behavior, or degradation of the drug or excipients, compromising the therapeutic efficacy of FDDS [52]. Therefore, meticulous attention to formulation design, selection of excipients, and manufacturing processes is necessary to ensure the stability of FDDS under various environmental conditions. Patient variability presents another challenge in the optimization and application of FDDS. Individual differences in gastric physiology, such as variations in gastric pH, fluid volume, and motility, can impact the effectiveness of FDDS across different patient populations [53]. For example, patients with gastrointestinal disorders or alterations in gastric function may exhibit altered drug absorption kinetics or reduced gastric retention of FDDS. Furthermore, factors such as age, gender, diet, and concomitant medications can also influence gastric physiology and affect the performance of FDDS. Therefore, personalized approaches to FDDS optimization may be necessary to accommodate individual patient characteristics and ensure optimal therapeutic outcomes [54].

6. Applications

Intragastric Floating Drug Delivery Systems (FDDS) offer a versatile platform for improving the treatment of various medical conditions by providing sustained drug release and enhancing bioavailability. One notable application of FDDS is in the treatment of peptic ulcers, where drugs such as antacids or antibiotics used to eradicate Helicobacter pylori infections can benefit from prolonged gastric retention [55]. By floating on the surface of gastric fluids, FDDS ensures continuous drug release, allowing for optimal drug exposure to the ulcer site and improving therapeutic outcomes. Another condition that can benefit from FDDS is gastroesophageal reflux disease (GERD), a chronic condition characterized by the reflux of stomach acid into the esophagus, leading to symptoms such as heartburn and acid regurgitation [56]. Drugs that reduce acid secretion, such as proton pump inhibitors (PPIs) or H2-receptor antagonists, are commonly used to manage GERD. FDDS can provide sustained release of these drugs, ensuring prolonged suppression of gastric acid production and effective symptom control [57]. By maintaining therapeutic drug levels in the stomach over an extended period, FDDS offers a convenient and efficient approach to managing GERD symptoms and improving patient quality of life. Parkinson's disease, a neurodegenerative disorder characterized by motor and non-motor symptoms, presents unique challenges in drug therapy due to the variability in drug absorption and the need for precise dosing to achieve optimal symptom control [58]. Levodopa, the mainstay of Parkinson's disease treatment, is absorbed primarily in the upper gastrointestinal tract. However, its absorption can be unpredictable and affected by factors such as food intake and gastric emptying rate. FDDS offers a solution to this challenge by providing enhanced bioavailability of levodopa through prolonged gastric retention [59]. By floating on gastric fluids, FDDS ensures sustained release of levodopa, leading to more consistent drug absorption and improved symptom control in patients with Parkinson's disease. Controlled drug release is another important application of FDDS, particularly for drugs that require a controlled release profile to maintain therapeutic levels over an extended period. By incorporating drug-loaded matrices or microspheres into the floating system, FDDS can achieve controlled and sustained drug release, minimizing fluctuations in plasma drug levels and reducing the need for frequent dosing [60]. This approach is particularly beneficial for managing chronic conditions such as hypertension, diabetes, or chronic pain, where maintaining stable drug concentrations is essential for optimal disease management and prevention of adverse events.

In summary, Intragastric Floating Drug Delivery Systems offer significant advantages in the treatment of various medical conditions, including peptic ulcers, GERD, Parkinson's disease, and controlled drug release [61]. By providing prolonged gastric retention, sustained drug release, and enhanced bioavailability, FDDS improves therapeutic outcomes, enhances patient compliance, and offers a promising approach to optimizing drug therapy across a wide range of therapeutic areas. As research and development efforts continue to advance, FDDS holds great promise as a versatile and effective drug delivery platform for improving patient care and treatment outcomes [62].

7. Conclusion

Intragastric Floating Drug Delivery Systems (FDDS) represent a breakthrough in pharmaceuticals, offering a

powerful means to enhance drug retention and bioavailability. By leveraging buoyancy principles, these systems enable prolonged drug release within the stomach, leading to improved therapeutic efficacy and patient outcomes. FDDS bridge the gap between drug administration and absorption, ensuring optimal drug effects. They significantly enhance drug bioavailability, particularly for medications absorbed in the stomach or upper intestine, resulting in more consistent therapeutic responses and improved symptom control. Additionally, FDDS reduce dosing frequency, enhancing patient compliance and simplifying treatment regimens, especially for chronic conditions requiring long-term therapy. Despite formulation challenges and variations in gastric conditions, ongoing research and technological advancements continue to refine FDDS, paving the way for their widespread adoption in modern pharmacotherapy. In conclusion, FDDS represent a paradigm shift in drug delivery, offering the potential to revolutionize treatment practices and improve patient care through prolonged drug release, enhanced bioavailability, and improved patient adherence.

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