INTERNATIONAL JOURNAL OF PHARMACEUTICAL SCIENCES
[ISSN: 0975-4725; CODEN(USA): IJPS00]
Journal Homepage: https://www.ijpsjournal.com

OPEN ACCESS

Review Article

Floating Tablet: A Comprehensive Review

Shrijit Ingle*, Dr. Amit Jaiswal, Sainath Wankhede

P.R. Pote Patil College of Pharmacy, Amravati, Maharashtra, India.

ARTICLE INFO

Published: 24 Nov 2026
Keywords:
Floating tablet, Gastroretentive drug delivery, Gastric residence time, Effervescent, Hydroxypropyl methylcellulose, Sodium bicarbonate, Floating lag time, 3D printing
DOI:
10.5281/zenodo.24497128

ABSTRACT

Oral controlled-release dosage forms are widely used, but their benefit is limited for drugs that are absorbed mainly in the stomach and upper small intestine, because a conventional sustained-release tablet quickly passes this absorption window. Gastroretentive drug delivery systems are intended to prolong the residence time of a dosage form in the stomach, and floating tablets are among the most extensively studied of these systems. This review describes the gastric physiology that governs retention, the approaches to gastric retention, the mechanisms and classification of floating systems, drug selection, polymers, gas-generating agents and other excipients, methods of preparation, in vitro and in vivo evaluation, kinetic modelling of drug release, selected case studies, marketed products, and recent advances including three-dimensional printing. The reviewed studies show that the most important formulation variables are the type and viscosity grade of the gel-forming polymer, the level of the gas-generating agent and the use of swelling agents. Optimised tablets in the reviewed reports floated within seconds to minutes and stayed buoyant for 12 to more than 24 h in vitro. Human evidence is limited and variable; a small X-ray study of ciprofloxacin tablets reported a mean gastric residence of about 320 minutes. Combination retention mechanisms, statistical optimisation and 3D printing are promising developments, but robust human studies are needed to confirm clinical benefit.

INTRODUCTION

1.1 Background

The oral route is the most widely used and most patient-acceptable route of drug administration. Conventional immediate-release tablets, however, release their drug load rapidly, so plasma concentrations rise and fall within a short period; for drugs with short half-lives this means frequent dosing, fluctuating plasma levels and poor compliance. Oral controlled-release systems overcome these limitations by releasing the drug at a predetermined rate over an extended period. A controlled-release system can only be as effective as the time it spends in the part of the gastrointestinal (GI)

***Corresponding Author:** Shrijit Ingle
Address: P.R. Pote Patil College of Pharmacy, Amravati, Maharashtra, India
Email ✉: ingaleshrijit77@gmail.com

Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

tract where the drug is absorbed. For drugs absorbed mainly in the stomach or proximal small intestine, a dosage form that moves quickly past this "absorption window" releases part of its dose where absorption is poor, and bioavailability falls.[1] The same problem affects drugs that are unstable or poorly soluble at the alkaline pH of the lower intestine, and drugs intended to act locally in the stomach, such as antacids or agents used against *Helicobacter pylori*.[2]

Gastroretentive drug delivery systems (GRDDS) are designed to remain in the stomach for several hours and so to prolong the gastric residence time (GRT) of the dosage form.[3] They can improve the bioavailability of drugs with a narrow absorption window, reduce dose frequency and reduce fluctuations in plasma concentration.[4] Among the approaches to gastric retention, the floating drug delivery system (FDDS) is one of the most extensively investigated. A floating system has a bulk density lower than that of gastric contents (about 1.004 g/cm³), so it remains buoyant without affecting the gastric emptying rate of other contents; while it floats the drug is released slowly, and the residual system is emptied afterwards.[3] The tablet is the most attractive format because it is made on conventional, scalable equipment and is physically robust, so this review focuses on floating tablets.

1.2 Historical Development

The main milestones in the floating-tablet literature are: the hydrodynamically balanced system (HBS) of Sheth and Tossounian (1984);[23] the effect of density on gastric emptying (1986);[9] intragastric buoyant preparations (1989);[40] a multiple-unit floating system (1991);[25] hollow microspheres (1992);[16] the "resultant weight" concept for buoyancy (1994);[20] a human in vivo study of prolonged gastric retention (1998);[21] optimised floating matrix tablets with measured gastric residence (2000);[22] foam-powder-based floating tablets (2003);[24] a review of swelling-type products (2019);[44] and a review of 3D-printed floating systems (2024).[34]

1.3 Rationale, Aim and Scope

Hundreds of original studies describe floating matrix tablets of individual drugs, and many reviews summarise the concepts,[5] but the information is scattered and often presented from a narrow viewpoint (a single polymer or drug). This review draws on freely available peer-reviewed articles retrieved from PubMed, PubMed Central and Google Scholar. Its aim is to give a structured, evidence-based account of floating tablets as gastroretentive systems: the gastric physiology that governs retention, mechanisms and classification, drugs and excipients, methods of preparation, evaluation (buoyancy, swelling, dissolution kinetics and in vivo studies), case studies, applications, limitations and marketed products, and recent advances such as three-dimensional (3D) printing. It is a literature-based review and reports no new experiments; quoted numbers apply to the specific formulations and test conditions of the cited articles, and the correlation between in vitro buoyancy and in vivo retention in humans is imperfect.

2. Gastric Physiology and Factors Affecting Gastric Retention

2.1 Anatomy and pH of the Stomach

The stomach is a J-shaped muscular organ divided into the fundus, body and antrum, with the pyloric sphincter forming the outlet to the duodenum. The proximal stomach acts as a reservoir, whereas the antrum churns and grinds food and propels it toward the pylorus.[4] Two features matter for floating tablets. First, the fasted stomach holds only a small volume of fluid, and a floating system can rise and stay buoyant only if enough fluid is present to hydrate the polymer; floating tablets are therefore taken with a glass of water or after a meal.[3,8] Second, the pylorus limits the size of particles that can leave the stomach in the fed state, which is the basis of swelling approaches,[12] while a tablet floating over the fundus is kept away from the pylorus, lowering the chance of early emptying.[3]

In healthy fasted adults gastric pH is strongly acidic (about 1 to 3); after a meal it rises transiently as food buffers the acid and then falls again.[6] In vitro tests commonly use 0.1 N hydrochloric acid (pH 1.2), a worst-case fasted environment; in the fed state the lower acidity can slow gas generation from carbonates and lengthen the floating lag time.[4]

2.2 Gastric Motility and the Migrating Motor Complex

In the fasted state the stomach shows a cyclical contractile pattern, the migrating motor complex (MMC), repeating about every two hours in four phases: phase I is quiescent; phase II has intermittent contractions of increasing intensity; phase III consists of short bursts of intense, regular contractions (the "housekeeper wave") that sweep undigested material, including large particles, out of the stomach; and phase IV is a brief transition back to phase I.[3] In the fed state the MMC is replaced by continuous contractions that reduce food to particles below about 1 to 2 mm, which then leave through the pylorus. Because the housekeeper wave is absent, large single-unit dosage forms taken with a meal are retained much longer than in the fasted state, [7] which is why gastroretentive tablets are usually tested after a light meal in human studies.[8]

2.3 Gastric Emptying and the Absorption Window

Liquids leave the stomach faster than solids, and emptying of solid dosage forms is irregular and difficult to predict. The emptying of units depends on their size and density as well as on food,[9] and variability between and within individuals is large.[10] Some drugs are absorbed preferentially in the upper GI tract because of specific transporters, high local solubility or a favourable pH, so their absorption window is narrow. [11] Ciprofloxacin is an example: it is better absorbed from the stomach and proximal small intestine, and a conventional extended-release form is less effective because absorption declines as the tablet moves distally.[8]

2.4 Factors Affecting Gastric Residence Time

Table 1: Factors Affecting Gastric Residence Time of Dosage Forms

Category	Factor	Effect on gastric residence
Dosage form	Density	Density below that of gastric fluid favours buoyancy and longer retention[9]
Dosage form	Size and shape	Larger units are retained until the housekeeper wave; shape may affect pyloric passage[12]
Dosage form	Single vs multiple unit	Multiple-unit systems empty more gradually and show less variability[13]
Physiological	Fed or fasted state; meal type	Fed state delays emptying (MMC absent); fatty, high-calorie meals prolong retention[4]
Physiological	Posture	Upright posture may favour floating forms; supine posture may reduce the benefit[3]
Patient-related	Age, disease, drugs	Emptying varies with age and diabetes;[7] anticholinergics and opioids slow it, prokinetics hasten it[4]

Gastric retention therefore cannot be reduced to a single formulation property such as density. A tablet that floats perfectly in a beaker may still be emptied in a fasted patient if a housekeeper wave arrives while it lies in the antrum rather than over the fundus.[3]

3. Approaches to Gastric Retention

Reviews group the strategies into low-density (floating), high-density (sinking), expandable or swelling, bioadhesive, magnetic and modified-shape systems;[14] many practical designs combine two mechanisms, such as floating with swelling or bioadhesion.[15] **Floating systems** achieve buoyancy by in situ gas generation, by air entrapped in a swollen hydrophilic gel layer, or by intrinsically low-density materials such as foam powder or hollow microspheres.[16] **High-density systems** sink into the antral folds; pellets of about 2.4 to 2.8 g/cm³ were made with heavy materials such as barium sulphate, zinc oxide and iron powder,[4] but the approach is hard to apply to tablets because the heavy filler leaves little room for drug, and clinical evidence is limited.[2]

Swelling systems become too large to pass the pylorus after imbibing gastric fluid; they are designed with a small swallowable form, an expanded gastric form and a final small form after drug release, and must be erodible to avoid obstruction.[12] Superporous hydrogel

composites have been studied in animals.[17] **Bioadhesive systems** use polymers such as carbomers, chitosan and sodium carboxymethyl cellulose, but are limited by rapid mucus turnover and the acidic environment,[2] and are therefore often combined with floating or swelling excipients, as in floating-bioadhesive ciprofloxacin tablets[15] and a swellable bioadhesive ofloxacin tablet.[18] **Magnetic systems** need an external magnet and have poor patient acceptability.[5] Table 2 compares the main approaches.

Table 2: Comparison of the Main Gastroretentive Approaches

Approach	Principle	Main advantage	Main limitation
Floating	Density < gastric fluid	Simple; compatible with tablet technology	Needs fluid in stomach; variable when fasted
High density	Density > 2 g/cm³ to sink	Independent of fluid volume	Hard to achieve in a human dose; little clinical proof
Swelling	Size increase on hydration	Prolonged retention	Risk of obstruction; needs biodegradable design
Mucoadhesive	Adhesion to mucosa	Site-specific contact	Mucus turnover; acidic environment
Magnetic	External magnet	Controllable	Poor patient acceptability

4. Floating Drug Delivery Systems

4.1 Principle of Floating

A floating system is a low-density system with enough buoyancy to float over the gastric contents for a prolonged time without affecting the gastric emptying rate; the drug is released slowly while it floats and the residual system is then emptied.[19] By Archimedes' principle the tablet floats when its density is lower than that of the medium. A useful tablet must also have a short "floating lag time" (the time to rise to the surface) and a long total floating time.[4] Timmermans and Moës showed that density alone does not guarantee retention and that the "resultant weight", the net force keeping the dosage form immersed or floating, is a better descriptor; a system close to neutral buoyancy may be pulled under by gastric mixing.[20] Human studies with floating forms showed prolonged retention in the fed state.[21] The net vertical force F on a tablet is

$$F = F_{buoyancy} - F_{gravity} = (D_f - D_s) \cdot g \cdot V$$

where D_f and D_s are the densities of fluid and tablet, g is gravitational acceleration and V is tablet volume. The tablet floats when F is positive; the net force equals the resultant weight.[20] Because tablet volume changes as it hydrates and evolves gas, F varies with time, so buoyancy must be followed over the whole test. For a cylindrical tablet, apparent density = W / ($\pi r^2 h$), which must be below that of gastric fluid (about 1.004 g/cm³).[3]

4.2 Classification of Floating Systems

Floating systems are classified by buoyancy mechanism into effervescent and non-effervescent systems,[3] and each may be single-unit (tablet, capsule) or multiple-unit (microspheres, granules).

Effervescent systems contain a gas-generating agent, typically sodium bicarbonate, sodium carbonate or calcium carbonate, often with an organic acid such as citric or tartaric acid. On contact with gastric acid, carbon dioxide is liberated and trapped in the gelled hydrocolloid layer, lowering the specific gravity of the tablet:[4]

$$NaHCO_3 + HCl \rightarrow NaCl + H_2O + CO_2\uparrow$$

A typical tablet is a matrix of a hydrophilic polymer, most commonly hydroxypropyl methylcellulose (HPMC), in which the gas former is dispersed; the hydrated polymer forms a gel layer that admits fluid but retains the gas.[22] In ciprofloxacin tablets the floating lag time fell as sodium bicarbonate was increased.[8] When citric acid is present it reacts with bicarbonate even in weakly acidic medium ($3NaHCO_3 + C_6H_8O_7 \rightarrow Na_3C_6H_5O_7 + 3H_2O + 3CO_2\uparrow$), and calcium carbonate gives gas more slowly than bicarbonate but adds no sodium load.[4] If the gel is weak or erodes quickly, the gas escapes and buoyancy is lost.[22]

Non-effervescent systems rely on swelling of hydrophilic polymers and air entrapment. The classic example is the HBS, in which drug and gel-forming hydrocolloids are filled into a capsule or compressed

into a tablet; the hydrated surface gel keeps the bulk density below one.[23] Streubel and co-workers compressed low-density polypropylene foam powder with drug and polymer to obtain tablets that floated immediately and released drug over many hours.[24] **Bilayer tablets** combine a buoyant sustained-release layer with an immediate-release layer that provides a loading dose.[19] **Multiple-unit systems** (hollow microspheres,[16] gas-forming pellets,[26] floating alginate beads[27]) show less variability in emptying and less risk of dose dumping because failure of one unit does not affect the rest.[25] Tablets offer established equipment, high throughput, low cost and stability, but a single-unit tablet is subject to "all-or-none" emptying, and an early-emptied tablet delivers its whole dose to the wrong site.[4]

4.3 Mechanism of Drug Release

In a hydrophilic matrix floating tablet, water penetrates and relaxes the polymer chains, a gel layer forms, the drug dissolves and diffuses through the gel, and at later times the outer layer erodes.[29] The balance of diffusion, swelling and erosion depends on polymer grade and concentration, drug solubility and tablet porosity, and can be identified by kinetic analysis. Sodium bicarbonate increases gel porosity and can accelerate release.[8]

5. Formulation of Floating Tablets

5.1 Selection of Drug Candidates

Suitable candidates are (i) drugs absorbed mainly in the stomach or upper small intestine, such as riboflavin and levodopa; (ii) drugs acting locally in the stomach, such as antacids and anti-*H. pylori* agents; (iii) drugs unstable in the intestine or colon, such as captopril; (iv) drugs poorly soluble at alkaline pH, such as diazepam, verapamil and chlordiazepoxide; and (v) drugs that disturb colonic bacteria, such as amoxicillin trihydrate.[5] Unsuitable candidates include drugs with very limited acid solubility, drugs unstable in gastric acid, mucosal irritants, and drugs well absorbed throughout the GI tract or with extensive first-pass metabolism.[3] Model drugs in the literature include ciprofloxacin,[8] ranitidine,[30] metformin,[31] carbamazepine,[32] ketoprofen[28] and furosemide.[33] Preformulation work includes solubility at pH 1.2 and at higher pH, stability in acid, dose and half-life, and drug-excipient compatibility by FTIR and DSC, especially with alkaline sodium bicarbonate.[3,4,35]

5.2 Components of a Floating Tablet

A floating matrix tablet contains the drug, a release-controlling hydrophilic polymer, a gas-generating agent (for effervescent systems), a filler, a binder (if wet granulated), a glidant and a lubricant; swelling agents, fatty excipients and an acidulant may be added to adjust buoyancy and release.[8] Table 3 compares the main polymers.

Table 3: Comparison of Polymers Used in Floating Tablets

Polymer	Nature	Main role in a floating tablet	Ref.
HPMC (K4M, K15M, K100M)	Semi-synthetic cellulose ether	Gel formation; higher-viscosity grades retain gas and slow release	[8,29]
Polyethylene oxide (PEO)	Synthetic, non-ionic	Strong gel with high swelling; often combined with HPMC	[31]
Carbomer (Carbopol)	Synthetic polyacrylic acid	Gel strength and bioadhesion; modifies release with HPMC	[32,51]
Guar gum	Natural galactomannan	Helps maintain device integrity; modifies release	[32]
Xanthan gum, sodium alginate, chitosan	Natural polysaccharides	Gel-forming, biodegradable alternatives to synthetic polymers	[2,27]
Sodium carboxymethyl cellulose	Semi-synthetic derivative	Bioadhesive component of floating-bioadhesive tablets	[15]

5.3 Polymers

HPMC is the most widely used polymer, available in several viscosity grades (K4M, K15M, K100M). Higher-viscosity grades form a stronger gel, slow drug release and retain gas better, which tends to prolong floating.[29] In ciprofloxacin hydrochloride tablets, formulations with the low-viscosity grade K100LV or with K15M showed poor swelling and integrity, whereas K100M gave good integrity, swelling and sustained release; the grade must be chosen empirically for each drug.[8] PEO swells strongly and is often combined with HPMC: in metformin tablets an HPMC–PEO (1:4) matrix with sodium bicarbonate and sodium starch glycolate, optimised by a Box-Behnken design, floated for more than 24 h with a lag time under 4 min.[31] Carbamazepine tablets with HPMC, guar gum and carbopol floated for 24 h or more, and guar gum helped to maintain integrity.[32]

5.4 Gas-Generating Agents, Swelling Agents and Other Adjuncts

Sodium bicarbonate is the commonest gas former because it is inexpensive, safe and reacts readily with acid; citric acid keeps gas generation going in less acidic (fed-state) contents.[4] Too little gas gives a long lag time, whereas too much can disrupt the gel, hasten erosion and speed release. In the ciprofloxacin study, raising sodium bicarbonate from 15% to 20% and 25% w/w of the drug shortened the lag time, but 20% and 25% differed little, so 20% was chosen as the optimum.[8] Its sodium content may be unwelcome in patients on sodium-restricted diets, for whom calcium carbonate may be used.[4]

Superdisintegrants such as crospovidone, croscarmellose sodium and sodium starch glycolate increase swelling so that the tablet also resists pyloric passage. In the ciprofloxacin study crospovidone gave the fastest and most consistent swelling and the shortest lag times, attributed to its wicking behaviour, whereas sodium starch glycolate swelled later and sometimes floated unstably.[8] Fatty excipients lower density and retard water penetration, and low-density materials such as foam powder help when the dose is large.[24]

5.5 Formulation Variables and Experimental Design

Floating and release depend on interacting variables. A higher polymer level and viscosity increase gel strength and floating duration but may prolong lag time;[31] more gas former shortens lag time and may speed release;[8] harder, less porous tablets float later because fluid penetration is slower;[4] highly soluble drugs release quickly and a high drug load leaves less polymer to form gel;[4] and soluble fillers such as lactose create channels and speed release, whereas insoluble fillers slow it.[29] Thin flat tablets hydrate quickly, large or elongated shapes may be retained longer,[12] and very large tablets are hard to swallow.[4]

Because so many variables interact, factorial, central composite and Box-Behnken designs are used to relate formulation variables to floating lag time, floating time and cumulative release with few runs. In the metformin study, seventeen formulations were run with polymer content, sodium bicarbonate and sodium starch glycolate as variables; the optimised tablets showed no major change in assay, dissolution or lag time after 3 months at 40 °C and 75% relative humidity.[31]

6. Methods of Preparation

Floating tablets use the unit operations of other matrix tablets (milling, blending, granulation if used, compression and optional coating); 3D printing has recently been added.[34] In **direct compression** the sieved drug and excipients are blended and compressed; it is the simplest route, but moisture must be controlled because it can start the effervescent reaction early.[4] **Wet granulation** improves flow and content uniformity;[8] in the ciprofloxacin study PVP K30 (5% w/v) in isopropyl alcohol was used, with swelling agents added half intra- and half extra-granularly, and a non-aqueous binder is preferred when effervescent components are present.[4,8] **Dry granulation** (slugging or roller compaction) suits heat- or moisture-sensitive drugs and avoids water and solvent.[4] **Melt granulation** uses a meltable wax or fatty binder that is solvent-free and also lowers density and sustains release.[4] Floating tablets can also be made by compressing low-density foam powder,[24] as bilayer or tri-layer tablets,[19] or by

additive manufacturing.[34] Table 4 compares the methods.

Table 4: Comparison of Methods Used to Prepare Floating Tablets

Method	Principle	Advantages	Limitations
Direct compression	Blend then compress	Few steps; no heat or water	Needs good flow and compress-ibility
Wet granulation	Binder liquid, then dry	Better flow and content uniformity	Moisture and heat; risk with effervescent agent
Dry granulation	Slugging or roller compaction	No moisture or heat	Dust and fines; more equipment
Melt granulation	Meltable binder	Solvent-free; lowers density	Needs heat-stable drug
3D printing	Layer-by-layer deposition	Custom geometry and dose	Scale-up and regulatory challenges

On scale-up, humidity and temperature of the compression room must be kept low, and the blend must be uniform because segregation of sodium bicarbonate makes lag time vary; in-process checks of weight, hardness and thickness and routine lag-time testing confirm consistency.[4,35] Effervescent tablets are moisture sensitive and are normally packed in aluminium strip or blister packs, with or without desiccant, and stability studies should be done in the final pack.[4] Typical problems include a long lag time (remedy: more gas former with citric acid, lower compression force, crospovidone),[4,8] loss of buoyancy or rapid release (remedy: higher-viscosity HPMC, PEO or guar gum, an insoluble filler),[29,31,32] and premature gas evolution (remedy: non-aqueous binder or dry granulation, humidity control).[4]

7. Evaluation of Floating Tablets

7.1 Pre- and Post-compression Evaluation

Pre-compression studies include drug-excipient compatibility (FTIR, DSC), bulk and tapped density, angle of repose, Carr's index and Hausner ratio.[35] Compatibility with the alkaline gas former is especially important for acid- or base-sensitive drugs. Flow indices are calculated as Carr's index (%) = [(tapped − bulk density) / tapped density] × 100 and Hausner ratio = tapped / bulk density; a Carr's index of 10% or less and a Hausner ratio of 1.00 to 1.11 indicate excellent flow.[45] Post-compression tests include thickness, weight variation, hardness (held at about 9 kg/cm² across the ciprofloxacin formulations to avoid its influence on floating), friability (loss below 1% is acceptable) and drug content, which ranged from about 93% to 105% of label claim in that study.[8] Friability (%) = [(W_1 − W_2) / W_1] × 100, where W_1 and W_2 are the weights before and after tumbling. USP limits for weight variation of uncoated tablets are ±10% (130 mg or less), ±7.5% (130 to 324 mg) and ±5% (more than 324 mg); floating tablets commonly weigh several hundred milligrams and so fall in the ±7.5% or ±5% categories.

7.2 In Vitro Buoyancy and Swelling Studies

The floating lag time (FLT) and total floating time (TFT) are measured by placing the tablet in 100 to 500 mL of 0.1 N HCl at 37 ± 0.5 °C and recording times visually; in the ciprofloxacin study a USP apparatus II vessel with 500 mL of medium at 50 rpm was used.[8] The commonly stated aim is a lag time as short as possible (under a minute to a few minutes) and a total floating time of at least 8 to 12 h, or longer for once-daily products.[4] Visual observation gives no information on buoyant force; the resultant-weight method of Timmermans and Moës measures the force needed to keep the tablet immersed and gives a continuous measure of buoyancy,[20] and Rosa and co-workers described a method for buoyant and bioadhesive properties.[36] Swelling is followed by weighing the tablet at intervals: swelling index (%) = [(W_t − W_0) / W_0] × 100, where W_t and W_0 are the swollen and initial weights.[8]

7.3 In Vitro Drug Release and Kinetic Modelling

Dissolution is normally measured with USP apparatus II (paddle) at 50 rpm and 37 ± 0.5 °C in 900 mL of 0.1 N HCl, sampling up to 12 or 24 h and analysing by UV spectrophotometry or HPLC;[8] a sinker is generally not

used because it prevents floating. Dissolution data are fitted to the models in Table 5 to learn the release mechanism.[37]

Table 5: Common Models Used to Analyse Release from Floating Matrix Tablets

Model	Equation	Interpretation
Zero order	$Q_t = Q_0 + K_0t$	Constant release rate; ideal for sustained release
First order	$\log Q_t = \log Q_0 - K_1t / 2.303$	Rate proportional to drug remaining
Higuchi[38]	$Q_t = K_H\sqrt{t}$	Fickian diffusion from a matrix
Korsmeyer–Peppas[39]	$M_t / M_\infty = K \cdot t^n$	Release exponent n indicates mechanism
Hixson–Crowell	$Q_0^{1/3} - Q_t^{1/3} = K_{HC}t$	Release with change in surface area

For cylindrical tablets, $n \leq 0.45$ indicates Fickian diffusion, $0.45 < n < 0.89$ anomalous (non-Fickian) transport in which diffusion and polymer relaxation or erosion both contribute, and $n \approx 0.89$ case-II transport.[29] In the ciprofloxacin study n lay between 0.45 and 0.85, and the optimised formulation followed the Higuchi model ($R^2 = 0.9806$, $n = 0.66$);[8] the metformin tablets best fitted Korsmeyer–Peppas.[31] Profiles are compared with the similarity factor $f2 = 50 \times \log \{[1 + (1/n)\Sigma(R_t - T_t)^2]^{-0.5} \times 100\}$, where R_t and T_t are reference and test dissolution at time t; f2 of 50 to 100 (and difference factor f1 of 0 to 15) indicates similar profiles.[37] The optimised ciprofloxacin formulation had f2 = 26.17, so its release differed from the marketed product, which released 92.8 ± 11.5% in 5 h.[8]

7.4 Stability Studies

Table 6 summarises the main tests and their usual acceptance criteria. Stability testing follows ICH conditions (for example 40 °C and 75% relative humidity for 6 months); for floating tablets lag time, floating time, swelling and release must also stay unchanged, since effervescent components are moisture sensitive.[4] The optimised metformin tablets were stable for 3 months under accelerated conditions.[31]

Table 6: Summary of the Main Tests for Floating Tablets and Their Typical Acceptance Criteria

Test	Method / medium	Typical criterion
Hardness	Monsanto / digital tester	Consistent; often 5 to 10 kg/cm² for matrix tablets (design dependent)
Friability	Roche friabilator, 100 revolutions	< 1% weight loss
Floating lag time	0.1 N HCl, 37 ± 0.5 °C	As short as possible (seconds to a few minutes)[4]
Total floating time	0.1 N HCl, 37 ± 0.5 °C	At least 8 to 12 h, or longer for once-daily products[4]
Swelling index	Weight gain in medium	Gradual increase; integrity maintained[8]
Dissolution	USP II, 50 rpm, 900 mL 0.1 N HCl	Sustained release over 8 to 24 h[8]
In vivo retention	X-ray or gamma scintigraphy	Prolonged gastric residence versus control[40,41]

7.5 In Vivo Evaluation

Gastric retention is most often shown by X-ray imaging with a radio-opaque marker such as barium sulphate, as used by Machida and colleagues.[40] In the ciprofloxacin study half of the drug was replaced by barium sulphate and the tablets were given to six healthy male volunteers; radiographs at 1 to 6 h gave a mean gastric residence of 320 ± 48.99 min, although late retention may partly reflect obstruction at the duodenum.[8] Barium sulphate changes tablet density, so the marked tablet is not identical to the actual formulation.[4] Gamma scintigraphy, in which the tablet is labelled with a gamma-emitting radionuclide, is generally the most informative technique, giving real-time information on emptying and the site of release;[41] in a classic study floating dosage forms were retained substantially longer than non-floating controls after a meal.[21] Final proof of benefit is pharmacokinetic: the AUC, C_{max}, T_{max} and half-life of the floating tablet are compared with immediate-release or conventional controlled-release products in a crossover design.[4]

Products that float well in vitro, and sometimes in animals, often perform less well in humans. Many floating systems were studied in dogs or other species whose gastric physiology differs from that of humans, so human studies are needed to validate claims of improved retention.[42] Fed state, fluid volume, posture and individual variability all affect results,[4] and combining floating with swelling or bioadhesion is therefore often preferred.[8]

8. Case Studies from the Published Literature

Ciprofloxacin hydrochloride. Arza and co-workers prepared swellable, floating, sustained-release tablets by wet granulation using HPMC (K4M, K100M and other grades), sodium bicarbonate, swelling agents and PVP K30; fourteen formulations were evaluated for swelling, floating, release and in vivo behaviour.[8] HPMC K100M gave good integrity and swelling (optimum polymer level 15% w/w of the drug), sodium bicarbonate at 20% w/w of the drug gave the best balance of lag time and release, and crospovidone gave the fastest swelling (about 3 h). The optimised formulation F12 had a floating lag time of about 15 s compared with 185 s for the marketed product (CIFRAN OD), followed the Higuchi model (n = 0.66) and showed a mean gastric residence of 320 ± 48.99 min in six volunteers.[8] The weaknesses are the small group and the absence of plasma data, so improved bioavailability was not directly shown.

Metformin hydrochloride. Senjoti and colleagues combined effervescence and swelling in tablets designed by a Box-Behnken design (seventeen formulations; HPMC–PEO 1:4, sodium bicarbonate and sodium starch glycolate as variables). The optimised tablets floated for more than 24 h with a lag time under 4 min, release best fitted Korsmeyer–Peppas, and accelerated stability for 3 months showed no major change; the evidence is in vitro only.[31]

Carbamazepine and ciprofloxacin (floating-bioadhesive). Kar and Reddy prepared non-disintegrating carbamazepine tablets with HPMC, guar gum, carbopol and sodium bicarbonate; release followed zero-order kinetics, higher-viscosity HPMC slowed release, and guar gum maintained integrity for 24 h or longer.[32] Varshosaz and co-workers combined flotation with bioadhesion in ciprofloxacin tablets containing sodium carboxymethyl cellulose, HPMC, polyacrylic acid and polymethacrylic acid, with citric acid and sodium bicarbonate as the gas-generating system, to offset the weakness of floating when gastric fluid is scarce.[15] Table 7 summarises these studies.

Table 7: Summary of Selected Floating Tablet Studies

Drug (ref.)	Key polymers / agents	Key findings	Evidence level
Ciprofloxacin HCl[8]	HPMC K100M, crospovidone, $NaHCO_3$	Short lag time; Higuchi, n = 0.66; residence 320 min	In vitro; in vivo (X-ray, n = 6)
Metformin HCl[31]	HPMC–PEO, $NaHCO_3$, SSG	Float > 24 h; lag < 4 min; stable 3 months	In vitro and stability
Carbamazepine[32]	HPMC, guar gum, carbopol, $NaHCO_3$	Zero-order release; integrity ≥ 24 h	In vitro
Ciprofloxacin HCl[15]	NaCMC, HPMC, polyacrylic acid, $NaHCO_3$	Floating plus bioadhesive extended release	In vitro

9. Applications, Advantages, Limitations and Marketed Products

9.1 Applications

Floating matrix tablets give sustained delivery over 12 h or longer, reducing dosing frequency for short half-life drugs;[3,4] metformin tablets have been studied in vitro and in vivo.[31,53] They suit site-specific delivery of drugs absorbed in the stomach and upper intestine, such as furosemide and riboflavin (bilayer furosemide tablets have been tested in vivo),[5,33,52] may improve absorption by keeping the drug near its absorption site (levodopa as an HBS is the standard example),[4,11] can hold antimicrobials or antacids against the gastric mucosa for local therapy such as *H. pylori* eradication,[43,50] and reduce colonic exposure to drugs such as amoxicillin trihydrate.[5]

9.2 Advantages and Limitations

Advantages: improved bioavailability of drugs absorbed in the upper GI tract;[4] sustained, predictable delivery with less plasma fluctuation and better compliance;[5] local gastric action;[43] less waste of drugs unstable or poorly soluble at intestinal pH;[4] and scalable, well-established tablet technology.[19] **Limitations:** they need enough gastric fluid to float, so patients should take them with water;[8] acid-unstable, irritant or widely absorbed drugs are unsuitable;[4] single-unit systems risk all-or-none emptying and high interindividual variability;[9] retention depends on posture, food and MMC phase, so benefit when fasted may be reduced;[21] high-dose, high-viscosity formulations give tablets that are hard to swallow;[4] effervescent components need protective packaging;[4] and in vitro results often over-predict in vivo performance.[42]

9.3 Marketed Gastroretentive Products

Several gastroretentive products based on floating, swelling, bioadhesive or raft-forming principles have reached the market (Table 8).[4] Swelling-type gastroretentive tablets for metformin and gabapentin have also been commercialised.[44] Availability differs by country and should be checked against current regulatory databases. The small number of products compared with the many published formulations reflects the difficulty of achieving reproducible retention and the cost of the human studies required for approval.[42]

Table 8: Examples of Gastroretentive Products Named in Published Reviews

Product	Active ingredient	Type of system
Madopar HBS	Levodopa and benserazide	Hydrodynamically balanced capsule
Valrelease	Diazepam	Floating capsule
Topalkan	Aluminium-magnesium antacid	Floating / alginate-based antacid
Liquid Gaviscon	Alginate and antacids	Raft-forming liquid
Cifran OD	Ciprofloxacin	Gastroretentive extended-release tablet
Conviron	Ferrous sulphate	Colloidal gel-forming floating system
Cytotec	Misoprostol	Bilayer floating capsule
Almagate Flatcoat	Almagate antacid	Floating antacid

10. Recent Advances and Future Perspectives

10.1 Three-Dimensional Printing

A 2024 review of 3D-printed gastroretentive floating systems summarised the printing-based designs proposed to date and the parameters controlling buoyancy and sustained release.[34] Printed geometry, infill and shell thickness can be tailored to give hollow, low-density structures that float without gas-generating agents, and doses can be personalised.[34] Printed devices commonly use fused deposition modelling (FDM) with drug-loaded hot-melt-extruded filaments, or semi-solid extrusion; a hollow chamber traps air for buoyancy while the shell controls fluid entry and release. Limitations include slow printing, the need for heat-stable drugs and polymers in FDM, regulatory uncertainty and difficult scale-up.[34] Original studies are summarised in Table 9.

Table 9: Examples of 3D-printed Floating and Gastroretentive Systems

Study	Printing approach	Reported design feature	Ref.
Chai et al. (2017)	FDM	Printed tablets for intragastric floating delivery of domperidone	[46]
Li et al. (2018)	3D extrusion-based printing	Novel gastro-floating tablet	[47]
Giri et al. (2020)	Hot-melt extrusion with FDM	Intragastric floating, controlled-release theophylline tablets	[48]
Charoenying et al. (2020)	3D printing of devices	Floating capsule in a printed gastro-retentive device for amoxicillin	[49]

10.2 Other Developments

Combination systems pair floating with swelling or bioadhesion (ciprofloxacin,[8,15] ofloxacin[18]) to maintain retention when fluid volume is low or the MMC sweeps the stomach. **Natural polymers** (guar gum, xanthan gum, alginate, chitosan) are biodegradable, inexpensive and of low toxicity, but batch-to-batch consistency needs study.[27] **Quality-by-design** and statistical optimisation are now standard.[31] A major gap is the lack of in vitro models that predict retention in humans: current tests use a static acid volume, whereas the stomach has fluctuating volume, mechanical forces and pH, so dynamic gastric models combined with non-invasive imaging in volunteers are needed.[42] Future directions include new indications such as local *H. pylori* therapy,[14] personalised 3D-printed tablets,[34] fixed-dose combinations for chronic diseases, and larger human studies with pharmacokinetic endpoints in fed and fasted states.

SUMMARY AND CONCLUSION

Floating tablets are a rational approach for drugs absorbed mainly in the stomach and proximal small intestine, drugs acting locally in the stomach, and drugs unstable or poorly soluble at alkaline pH. Gastric physiology, especially the fasted-state MMC and fed-state motility, sets the framework for any gastroretentive design. Buoyancy is achieved by gas generation or by polymer swelling, and composition is dominated by a gel-forming polymer such as HPMC and a gas former such as sodium bicarbonate; the polymer type and viscosity grade, the gas-former level and the use of swelling agents are the most important determinants of floating and release. The case studies show that optimised tablets float within seconds to a few minutes and remain buoyant for 12 to more than 24 h in vitro, with the sole human data set discussed, a small X-ray study, reporting a mean gastric residence of about 5 h.[8,31] Most published evidence is in vitro, and in vivo retention is variable. Human studies remain essential, and 3D printing, combination mechanisms and natural polymers offer ways to improve and personalise gastroretentive therapy but require further validation and regulatory clarity.

REFERENCES

1. Rouge N, Buri P, Doelker E: Drug absorption sites in the gastrointestinal tract and dosage forms for site-specific delivery. Int J Pharm 1996; 136 (1-2):117-139.
2. Streubel A, Siepmann J, Bodmeier R: Gastroretentive drug delivery systems. Expert Opin Drug Deliv 2006; 3 (2):217-233.
3. Singh BN, Kim KH: Floating drug delivery systems: an approach to oral controlled drug delivery via gastric retention. J Control Release 2000; 63 (3):235-259. doi:10.1016/S0168-3659 (99)00204-7.
4. Arora S, Ali J, Ahuja A, Khar RK, Baboota S: Floating drug delivery systems: a review. AAPS PharmSciTech 2005; 6 (3):E372-390. doi:10.1208/pt060347. PMID: 16353995.
5. Pawar VK, Kansal S, Garg G, Awasthi R, Singodia D, Kulkarni GT: Gastroretentive dosage forms: a review with special emphasis on floating drug delivery systems. Drug Deliv 2011; 18 (2):97-110.
6. Dressman JB, Berardi RR, Dermentzoglou LC, Russell TL, Schmaltz SP, Barnett JL, et al: Upper gastrointestinal (GI) pH in young, healthy men and women. Pharm Res 1990; 7 (7):756-761.
7. Hwang SJ, Park H, Park K: Gastric retentive drug-delivery systems. Crit Rev Ther Drug Carrier Syst 1998; 15 (3):243-284.
8. Arza RAK, Gonugunta CSR, Veerareddy PR: Formulation and evaluation of swellable and floating gastroretentive ciprofloxacin hydrochloride tablets. AAPS PharmSciTech 2009; 10 (1):220-226. doi:10.1208/s12249-009-9200-y. Available from: https://pmc.ncbi.nlm.nih.gov/articles/PMC2663690/
9. Davis SS, Stockwell AF, Taylor MJ, Hardy JG, Whalley DR, Wilson CG, et al: The effect of density on the gastric emptying of single- and multiple-unit dosage forms. Pharm Res 1986; 3 (4):208-213.
10. Moës AJ: Gastroretentive dosage forms. Crit Rev Ther Drug Carrier Syst 1993; 10 (2):143-195.

11. Davis SS: Formulation strategies for absorption windows. Drug Discov Today 2005; 10 (4):249-257.
12. Klausner EA, Lavy E, Friedman M, Hoffman A: Expandable gastroretentive dosage forms. J Control Release 2003; 90 (2):143-162. doi:10.1016/S0168-3659 (03)00203-7.
13. Efentakis M, Koutlis A, Vlachou M: Development and evaluation of oral multiple-unit and single-unit hydrophilic controlled-release systems. AAPS PharmSciTech 2000; 1 (4):E34. doi:10.1208/pt010434.
14. Lopes CM, Bettencourt C, Rossi A, Buttini F, Barata P: Overview on gastroretentive drug delivery systems for improving drug bioavailability. Int J Pharm 2016; 510 (1):144-158.
15. Varshosaz J, Tavakoli N, Roozbahani F: Formulation and in vitro characterization of ciprofloxacin floating and bioadhesive extended-release tablets. Drug Deliv 2006; 13 (4):277-285. doi:10.1080/10717540500395106.
16. Kawashima Y, Niwa T, Takeuchi H, Hino T, Itoh Y: Hollow microspheres for use as a floating controlled drug delivery system in the stomach. J Pharm Sci 1992; 81 (2):135-140. doi:10.1002/jps.2600810207.
17. Chen J, Blevins WE, Park H, Park K: Gastric retention properties of superporous hydrogel composites. J Control Release 2000; 64 (1-3):39-51. doi:10.1016/S0168-3659 (99)00139-X.
18. Chavanpatil MD, Jain P, Chaudhari S, Shear R, Vavia PR: Novel sustained release, swellable and bioadhesive gastroretentive drug delivery system for ofloxacin. Int J Pharm 2006; 316 (1-2):86-92. doi:10.1016/j.ijpharm.2006.02.038.
19. Sopyan I, Pertiwi AP, Mu'tashim MN, et al: A novel of floating tablet delivery system as a tool to enhance absorption of drug: a review. Indones J Pharm 2020; 2 (1):27-33. doi:10.24198/id-jp.v2i1.26103.
20. Timmermans J, Moës AJ: Factors controlling the buoyancy and gastric retention capabilities of floating matrix capsules: new data for reconsidering the controversy. J Pharm Sci 1994; 83 (1):18-24.
21. Whitehead L, Fell JT, Collett JH, Sharma HL, Smith AM: Floating dosage forms: an in vivo study demonstrating prolonged gastric retention. J Control Release 1998; 55 (1):3-12.
22. Baumgartner S, Kristl J, Vrecer F, Vodopivec P, Zorko B: Optimisation of floating matrix tablets and evaluation of their gastric residence time. Int J Pharm 2000; 195 (1-2):125-135. doi:10.1016/S0378-5173 (99)00378-6.
23. Sheth PR, Tossounian J: The hydrodynamically balanced system (HBS): a novel drug delivery system for oral use. Drug Dev Ind Pharm 1984; 10 (2):313-339.
24. Streubel A, Siepmann J, Bodmeier R: Floating matrix tablets based on low density foam powder: effects of formulation and processing parameters on drug release. Eur J Pharm Sci 2003; 18 (1):37-45. doi:10.1016/S0928-0987 (02)00223-3.
25. Ichikawa M, Watanabe S, Miyake Y: A new multiple-unit oral floating dosage system. I: Preparation and in vitro evaluation of floating and sustained-release characteristics. J Pharm Sci 1991; 80 (12):1062-1066.
26. Sungthongjeen S, Paeratakul O, Limmatvapirat S, Puttipipatkhachorn S: Preparation and in vitro evaluation of a multiple-unit floating drug delivery system based on gas formation technique. Int J Pharm 2006; 324 (2):136-143.
27. Srinath A, Pandit JK: Multiple-unit floating alginate system: effect of additives on ciprofloxacin release. Drug Deliv 2008; 15 (7):471-476. doi:10.1080/10717540802329282.
28. El-Kamel AH, Sokar MS, Al Gamal SS, Naggar VF: Preparation and evaluation of ketoprofen floating oral delivery system. Int J Pharm 2001; 220 (1-2):13-21. doi:10.1016/S0378-5173 (01)00574-9.
29. Siepmann J, Peppas NA: Modeling of drug release from delivery systems based on hydroxypropyl methylcellulose (HPMC). Adv Drug Deliv Rev 2001; 48 (2-3):139-157.

30. Dave BS, Amin AF, Patel M: Gastroretentive drug delivery system of ranitidine hydrochloride: formulation and in vitro evaluation. AAPS PharmSciTech 2004; 5 (2):e34.
31. Senjoti FG, Mahmood S, Jaffri JM, et al: Design and in-vitro evaluation of sustained release floating tablets of metformin HCl based on effervescence and swelling. Iran J Pharm Res 2016; 15 (1):53-70. Available from: https://pmc.ncbi.nlm.nih.gov/articles/PMC4986121/
32. Kar M, Reddy MS: Design and in vitro evaluation of floating drug delivery system for an antipsychotic agent: a technical report. PDA J Pharm Sci Technol 2006; 60 (6):389-394.
33. Menon A, Ritschel WA, Sakr A: Development and evaluation of a monolithic floating dosage form for furosemide. J Pharm Sci 1994; 83 (2):239-245.
34. Mora-Castaño G, Domínguez-Robles J, Himawan A, Millán-Jiménez M, Caraballo I: Current trends in 3D printed gastroretentive floating drug delivery systems: a comprehensive review. Int J Pharm 2024; 663:124543. doi:10.1016/j.ijpharm.2024.124543.
35. Gupta P, Kesh M: Formulation and evaluation of gastro-retentive floating tablets. Int J Pharm Biol Sci Arch 2018; 6 (6):1-11.
36. Rosa M, Zia H, Rhodes T: Dosing and testing in-vitro of a bioadhesive and floating drug delivery system for oral application. Int J Pharm 1994; 105 (1):65-70.
37. Costa P, Sousa Lobo JM: Modeling and comparison of dissolution profiles. Eur J Pharm Sci 2001; 13 (2):123-133.
38. Higuchi T: Mechanism of sustained-action medication. Theoretical analysis of rate of release of solid drugs dispersed in solid matrices. J Pharm Sci 1963; 52:1145-1149.
39. Korsmeyer RW, Gurny R, Doelker E, Buri P, Peppas NA: Mechanisms of solute release from porous hydrophilic polymers. Int J Pharm 1983; 15 (1):25-35.
40. Machida Y, Inouye K, Tokumura T, Iwata M, Nagai T: Preparation and evaluation of intragastric buoyant preparations. Drug Des Deliv 1989; 4 (2):155-161. PMID: 2765108.
41. Iannuccelli V, Coppi G, Sansone R, Ferolla G: Air compartment multiple-unit system for prolonged gastric residence. Part II. In vivo evaluation. Int J Pharm 1998; 174 (1-2):55-62.
42. Mandal UK, Chatterjee B, Senjoti FG: Gastro-retentive drug delivery systems and their in vivo success: a recent update. Asian J Pharm Sci 2016; 11 (5):575-584.
43. Bardonnet PL, Faivre V, Pugh WJ, Piffaretti JC, Falson F: Gastroretentive dosage forms: overview and special case of Helicobacter pylori. J Control Release 2006; 111 (1-2):1-18.
44. Tripathi J, Thapa P, Maharjan R, Jeong SH: Current state and future perspectives on gastroretentive drug delivery systems. Pharmaceutics 2019; 11 (4):193.
45. Carr RL: Evaluating flow properties of solids. Chem Eng 1965; 72:163-168.
46. Chai X, Chai H, Wang X, Yang J, Li J, Zhao Y, et al: Fused deposition modeling (FDM) 3D printed tablets for intragastric floating delivery of domperidone. Sci Rep 2017; 7:2829. doi:10.1038/s41598-017-03097-x.
47. Li Q, Guan X, Cui M, Zhu Z, Chen K, Wen H, et al: Preparation and investigation of novel gastro-floating tablet with 3D extrusion-based printing. Int J Pharm 2018; 535 (1-2):325-332.
48. Giri BR, Song ES, Kwon J, Lee JH, Park JB, Kim DW: Fabrication of intragastric floating, controlled release 3D printed theophylline tablets using hot-melt extrusion and fused deposition modeling. Pharmaceutics 2020; 12 (1):77.
49. Charoenying T, Patrojanasophon P, Ngawhirunpat T, Rojanarata T, Akkaramongkolporn P, Opanasopit P: Fabrication of floating capsule-in-3D-printed devices as gastro-retentive delivery systems of amoxicillin. J Drug Deliv Sci Technol 2020; 55:101393.
50. Yang L, Eshraghi J, Fassihi R: A new intragastric delivery system for the treatment of Helicobacter

pylori associated gastric ulcers: in vitro evaluation. J Control Release 1999; 57 (3):215-222.

51. Li S, Lin S, Daggy BP, Mirchandani HL, Chien YW: Effect of HPMC and Carbopol on the release and floating properties of gastric floating drug delivery system using factorial design. Int J Pharm 2003; 253 (1-2):13-22.
52. Ozdemir N, Ordu S, Ozkan Y: Studies of floating dosage forms of furosemide: in vitro and in vivo evaluations of bilayer tablet formulations. Drug Dev Ind Pharm 2000; 26 (8):857-866.
53. Ali J, Arora S, Ahuja A, Babbar AK, Sharma RK, Khar RK, et al: Formulation and development of hydrodynamically balanced system for metformin: in vitro and in vivo evaluation. Eur J Pharm Biopharm 2007; 67 (1):196-201.

HOW TO CITE: Shrijit Ingle, Dr. Amit Jaiswal, Sainath Wankhede, Floating Tablet: A Comprehensive Review, Int. J. of Pharm. Sci., 2026, Vol 4, Issue 11, 4407-4420. https://doi.org/10.5281/zenodo.24497128