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Review Article

A REVIEW ON: GASTRORETENTIVE FLOATING DRUG DELIVERY SYSTEM

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Technological attempts have been made in the research and development of rate-controlled oral drug delivery systems to overcome physiological adversities, such as short gastric residence times (GRT) and unpredictable gastric emptying times (GET). It is known that differences in gastric physiology, such as, gastric pH, and motility exhibit both intra- as well as inter-subject variability demonstrating significant impact on gastric retention time and drug delivery behaviour. This triggered the attention towards formulation of stomach specific (gastro retentive) dosage forms. This dosage forms will be very much useful to deliver 'narrow absorption window' drugs. Several approaches are currently utilized in the prolongation of the GRT, including floating drug delivery systems (FDDS), swelling and expanding systems, polymeric bioadhesive systems, high-density systems, modified-shape systems and other delayed gastric emptying devices. In this review, current & recent developments of Stomach Specific FDDS are discussed.

Key Words: - Gastric residence time, floating drug delivery system, hydrodynamically balanced system, effervescent, non- effervescent.

INTRODUCTION

The oral route is increasingly being used for the delivery of therapeutic agents because the low cost of the therapy and ease of administration lead to high levels of patient compliance. More than 50% of the drug delivery systems available in the market are oral drug delivery systems¹. Controlled release drug delivery systems (CRDDS) provide drug release at a predetermined, predictable, and controlled rate. Controlled release drug delivery system is capable of achieving the benefits like maintenance of optimum therapeutic drug concentration in blood with predictable and reproducible release rates for extended time period; enhancement of activity of duration for short half life drugs; elimination of side effects; reducing frequency of dosing and wastage of

drugs; optimized therapy and better patient compliances^{2,3}. The successful development of oral controlled drug delivery systems requires an understanding of the three aspects of the system, namely. The physiochemical characteristics of the drug Anatomy and physiology of GIT and Characteristics of Dosage forms⁴

Good fundamental understanding of the anatomic and physiological characteristics of the human GIT is required to modulate the gastrointestinal transit time of a drug through FDDS for maximal gastrointestinal absorption of drugs and site specific delivery⁵.

Gastrointestinal retention

Gastro retentive systems can remain in the gastric region for several hours and hence

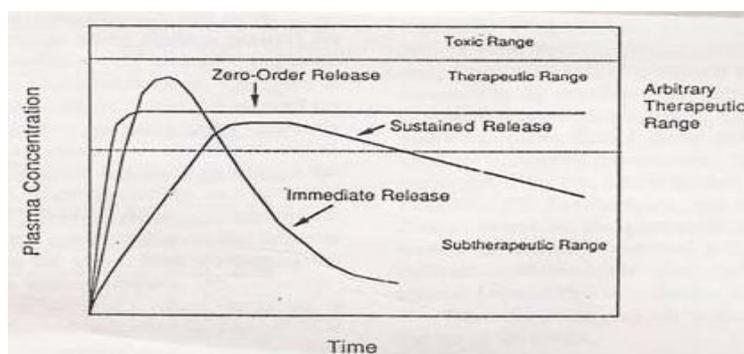


Fig. 1.1: Drug level versus time profile showing differences between zero order, controlled releases, slow first order sustained release and release from conventional tablet

significantly prolong the gastric residence time of drugs. Prolonged gastric retention improves bioavailability, reduces drug waste, and improves solubility for drugs that are less soluble in a high pH environment. It has applications also for local drug delivery to the stomach and proximal small intestines. Gastro retention helps to provide better availability of new products with new therapeutic possibilities and substantial benefits for patients⁵.

To successfully modulate the gastrointestinal transit time of a drug delivery system through floating drug delivery system (FDDS) For maximal gastrointestinal absorption of drugs and site specific delivery, one needs to have a good fundamental understanding of the anatomic and physiological characteristics of the human GIT. These are outlined and briefly discussed¹.

Stomach anatomy

The main function of the stomach is to process and transport food. It serves as a short term

storage reservoir, allowing a rather large meal to be consumed quickly. Substantial enzymatic digestion is initiated in stomach, particularly of proteins. Vigorous contractions of gastric smooth muscle mix and grind foodstuffs with gastric secretions, resulting in liquefaction of food. As food is liquefied in the stomach, it is slowly released into the small intestine for further processing⁶.

Anatomically the stomach is divided into 3 regions: fundus, body, and antrum (pylorus). The proximal part made of fundus and body acts as a reservoir for undigested material, whereas the antrum is the main site for mixing motions and act as a pump for gastric emptying by propelling actions⁷.

It has been reported that the mean value of pH in fasted healthy subjects is 1.1 ± 0.15 . But when food comes into the stomach, the pH may rise to levels in the 3.0 to 4.0 level due to the buffering capacity of proteins. However, in fasted state, basal gastric secretion in women



is slightly lower than that of men⁸.

Gastric emptying occurs during fasting as well as fed states. The pattern of motility is however distinct in the 2 states. During the fasting state an interdigestive series of electrical events take place, which cycle both through stomach and intestine every 2 to 3 hours. This is called the interdigestive myoelectric cycle or migrating myoelectric cycle (MMC), which is further divided into following 4 phases

1. Phase I (Basal phase) lasts from 30 to 60 minutes with rare contractions.
2. Phase II (Preburst phase) lasts for 20 to 40 minutes with intermittent action potential and contractions. As the phase progresses the intensity and frequency also increases gradually.

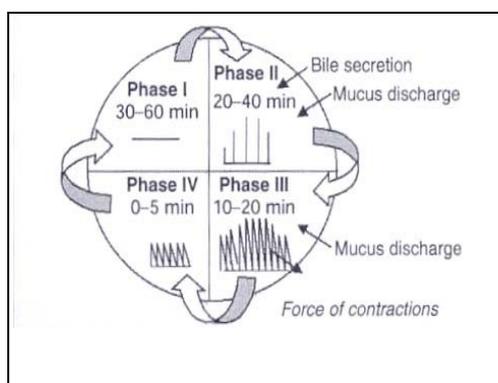


Fig. 1: Motility pattern in GIT

3. Phase III (burst phase) lasts for 10 to 20 minutes. It includes intense and regular contractions for short period. It is due to this wave that all the undigested material is swept out of the stomach down to the small intestine. It is also known as the housekeeper wave.

4. Phase IV lasts for 0 to 5 minutes and

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occurs between phases III and I of 2 consecutive cycles.

FACTORS AFFECTING GASTRIC RESIDENCE TIME OF FDDS

Formulation factors

Size of tablets

Retention of floating dosage forms in stomach depends on the size of tablets. Small tablets are emptied from the stomach during the digestive phase, but large ones are expelled during the house keeping waves⁹.

Floating and nonfloating capsules of 3 different sizes having a diameter of 4.8 mm (small units), 7.5 mm (medium units), and 9.9 mm (large units), were formulated and analyzed for their different properties. It was found that floating dosage units remained buoyant regardless of their sizes on the gastric contents throughout their residence in the gastrointestinal tract, while the nonfloating dosage units sank and remained in the lower part of the stomach. Floating units away from the gastroduodenal junction were protected from the peristaltic waves during digestive phase while the nonfloating forms stayed close to the pylorus and were subjected to propelling and retropelling waves of the digestive phase¹⁰.

Density of tablets

Density is the main factor affecting the gastric residence time of dosage form. A buoyant dosage form having a density less than that of the gastric fluids floats, since it is away from



the pyloric sphincter, the dosage unit is retained in the stomach for a prolonged period. A density of less than 1.0g/ml i.e. less than that of gastric contents has been reported. However, the floating force kinetics of such dosage form has shown that the bulk density of a dosage form is not the most appropriate parameter for describing its buoyancy capabilities¹¹.

Shape of tablets

The shape of dosage form is one of the factors that affect its gastric residence time. Six shapes (ring tetrahedron, cloverleaf, string, pellet, and disk) were screened in vivo for their gastric retention potential. The tetrahedron (each leg 2cm long) rings (3.6 cm in diameter) exhibited nearly 100% retention at 24 hr¹².

Viscosity grade of polymer

Drug release and floating properties of FDDS are greatly affected by viscosity of polymers and their interaction. Low viscosity polymers (e.g., HPMC K100 LV) were found to be more beneficial than high viscosity polymers (e.g., HPMC K4M) in improving floating properties. In addition, a decrease in the release rate was observed with an increase in polymer viscosity¹³.

a) Idiosyncratic factors

Gender

Women have slower gastric emptying time than do men. Mean ambulatory GRT in meals (3.4 ± 0.4 hours) is less compared with their age and race matched female counterparts

(4.6 ± 1.2 hours), regardless of the weight, height and body surface⁴.

Age

Low gastric emptying time is observed in elderly than do in younger subjects. Intrasubject and intersubject variations also are observed in gastric and intestinal transit time. Elderly people, especially those over 70 years have a significantly longer GRT¹⁴.

Posture

i) Upright position

An upright position protects floating forms against postprandial emptying because the floating form remains above the gastric contents irrespective of its size¹⁴.

Floating dosage forms show prolonged and more reproducible GRTs while the conventional dosage form sink to the lower part of the distal stomach from where they are expelled through the pylorus by antral peristaltic movements¹⁵.

ii) Supine position

This position offers no reliable protection against early and erratic emptying. In supine subjects large dosage forms (both conventional and floating) experience prolonged retention. The gastric retention of floating forms appear to remain buoyant anywhere between the lesser and greater curvature of the stomach. On moving distally, these units may be swept away by the peristaltic movements that propel the gastric contents towards the pylorus, leading to significant reduction in GRT compared with upright subjects¹⁶.



Concomitant intake of drugs

Drugs such as prokinetic agents (e.g., metoclopramide and cisapride), anti Cholinergics (e.g., atropine or propantheline), opiates (e.g., codeine) may affect the performance of FDDS. The co administration of GI motility decreasing drugs can increase gastric emptying time¹⁶.

Feeding regimen

Gastric residence time increases in the presence of food, leading to increased drug dissolution of the dosage form at the most favorable site of absorption. A GRT of 4 - 10 h has been reported after a meal of fats and proteins¹⁷.

SUITABLE DRUGS FOR GASTRORETENTION

Delivery of the Drugs in continuous and controlled manner have a lower level of side effects and provide their effects without the need for repeated dosing or with a low dosage frequency. Sustained release in the stomach is also useful for therapeutic agents that the stomach does not readily absorb, since sustained release prolongs the contact time of the agent in the stomach or in the upper part of the small intestine, from where absorption occurs and contact time is limited. Appropriate candidates for controlled release gastroretentive dosage forms are molecules that have poor colonic absorption but are characterized by better absorption properties at the upper parts of the GIT.

1. Narrow absorption window in GI tract, e.g., riboflavin and levodopa
2. Basically absorbed from stomach and upper part of GIT, e.g., chlordiazepoxide and cinnarazine.
3. Drugs that disturb normal colonic bacteria, e.g., amoxicillin trihydrate.
4. Locally active in the stomach, e.g., antacids and misoprostol.
5. Drugs that degrade in the colon, e.g., ranitidine HCl and metronidazole.

APPROACHES TO GASTRORETENTION

Several techniques are reported in the literature to increase the gastric retention of drugs¹⁶⁻¹⁹.

1) High-density systems

These systems, which have a density of $\sim 3\text{g/cm}^3$, are retained in the rugae of stomach and capable of withstanding its peristaltic movements^{18, 20}.

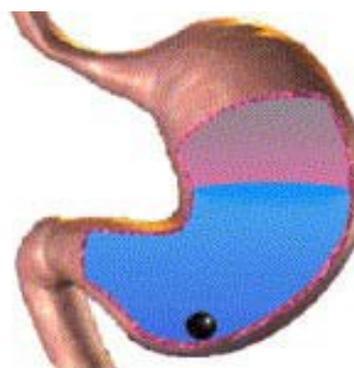


Fig. 2: High density systems

The only major drawback with these systems is that it is technically difficult to manufacture them with a large amount of drug (>50%) and achieve required density of 2.4 - 2.8g/cm³. Diluents such as barium sulphate (density=



4.9), zinc oxide, titanium oxide, and iron powder must be used to manufacture such high density formulation¹⁶.

2) Swelling and expanding systems

These systems are also called as “Plug type system”, since they exhibit tendency to remain logged in the pyloric sphincters. These polymeric matrices remain in the gastric cavity .

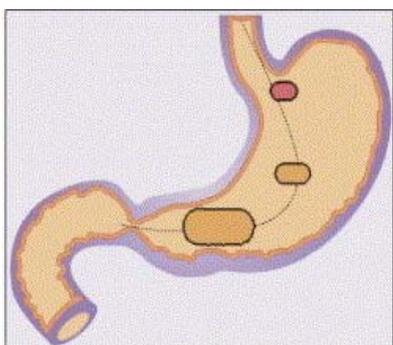


Fig.3: Swellable tablet in stomach

for several hours even in fed state²¹By selection of polymer with the proper molecular weight and swelling properties controlled and sustained drug release can be achieved. Upon coming in contact with gastric fluid, the polymer imbibes water and swells. The extensive swelling of these polymers is a result of the presence of physical & chemical cross links in the hydrophilic polymer network. These cross link prevents the dissolution of polymer and thus maintain the physical integrity of the dosage form. A high degree of cross linking retards the swelling ability of the system and maintains its physical integrity for prolonged period. On the other hand, a low degree of cross linking results in extensive swelling followed by the rapid dissolution of polymer²².

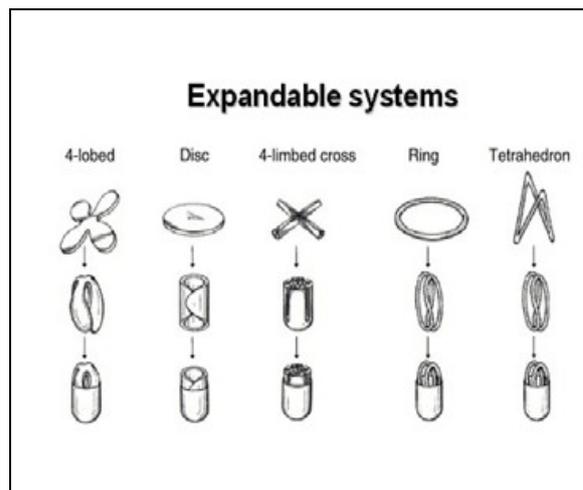


Fig. 4: Different geometric forms of unfoldable systems

3) Incorporating delaying excipients

Another delayed gastric emptying approach of interest include feeding of digestible polymers or fatty acid salts that changes the motility pattern, of the stomach to a fed stage thereby decreasing the gastric emptying rate and permitting considerable prolongation of the drug release. Prolongation of GRT of drug delivery system consists of incorporating delaying excipients like trietanolamine myristate in a delivery system²³.

4) Modified systems

Systems with non disintegrating geometric shape molded from silastic elastomers or extruded from polyethylene blends, which extend the GRT depending on size, shape and flexural modules of drug delivery device²⁴.

5) Mucoadhesive & bioadhesive systems

Bioadhesive drug delivery systems are used to localize a delivery device within the lumen to enhance the drug absorption in a site specific manner. This approach involves the use of



bioadhesive polymers, which can adhere to the epithelial surface in the stomach. Some of the most promising excipients that have been used commonly in these systems include polycarbophil, carbopol, lectins, chitosan, CMC and gliadin, etc ^{25, 26}.

6) Floating systems

Floating drug delivery systems (FDDS) have a bulk density less than gastric fluids and so remain buoyant in the stomach without affecting the gastric emptying rate for a prolonged period of time. While the system is floating on the gastric contents, the drug is released slowly at the desired rate from the system. After release of drug, the residual system is emptied from the stomach²⁷. Floation of a drug delivery system in the stomach can be achieved by incorporating floating chamber filled with vacuum, air, or inert gas.

CLASSIFICATION OF FDDS BASED ON MECHANISM OF BUOYANCY

a) Single unit

Single unit dosage forms are easiest to develop but suffers from the risk of losing their effects too early due to their all or none emptying from the stomach and, thus they may cause high variability in bioavailability and local irritation due to large amount of drug delivered at a particular site of the gastro intestinal tract²⁸.

Non-effervescent systems

One or more gel forming, highly swellable, cellulosic hydrocolloids (e.g. hydroxyl ethyl

cellulose, hydroxyl propyl cellulose, hydroxypropyl methyl cellulose [HPMC] and sodium carboxy methyl cellulose), polysaccharides, or matrix forming polymers(e.g., polycarbophil, polyacrylates, and polystyrene) are incorporated in high level (20 - 75% w/w) to tablets or capsules ^{29, 30}.

For the preparation of these types of systems, the drug and the gel forming hydrocolloid are mixed thoroughly. After oral administration this dosage form swells in contact with gastric fluids and attains a bulk density of < 1 . The air entrapped within the swollen matrix imparts buoyancy to the dosage form. The so formed swollen gel like structure acts as a reservoir and allows sustained release of drug through the gelatinous mass.

Effervescent systems or gas generating systems

These are matrix types of systems prepared with the help of swellable polymers such as methylcellulose and chitosan and various effervescent compounds, e.g. sodium bicarbonate, tartaric acid, and citric acid. They are formulated in such a way that when in contact with the acidic gastric contents, CO₂ is liberated and gets entrapped in swollen hydrocolloids, which provides buoyancy to the dosage forms. The optimal stoichiometric ratio of citric acid and sodium bicarbonate for gas generation is reported to be 0.76:1.

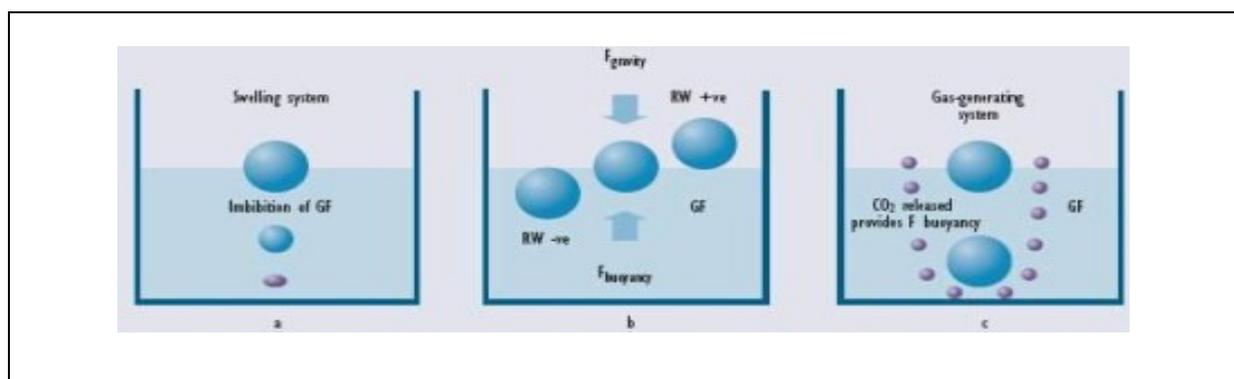


Fig. 1.6: The mechanism of floating systems

b) Multiple unit

Single unit formulations are associated with problems such as sticking together or being obstructed in gastrointestinal tract, which may have a potential danger of producing irritation. Multiple unit systems avoid the 'all or none' gastric emptying nature of single unit systems. It reduces the intersubject variability in absorption and the probability for dose dumping is lower³¹.

Non-effervescent systems

A little or no much report was found in the literature on non effervescent multiple unit systems, as compared to the effervescent systems. However, few workers have reported the possibility of developing such system containing indomethacin, using chitosan as the polymeric excipient. A multiple unit HBS containing indomethacin as a model drug prepared by extrusion process is reported. A mixture of drug, chitosan and acetic acid is extruded through a needle, and the extrudate is cut and dried. Chitosan hydrates float in the

acidic media, and the required drug release could be obtained by modifying the drug polymer ratio.

Effervescent systems

A multiple unit system comprises of calcium alginate core and calcium alginate/PVA membrane, both separated by an air compartment was prepared. In presence of water, the PVA leaches out and increases the membrane permeability, maintaining the integrity of the air compartment. Increase in molecular weight and concentration of PVA, resulted in enhancement of the floating properties of the system. Freeze drying technique is also reported for the preparation of floating calcium alginate beads. Sodium alginate solution is added drop wise into the aqueous solution of calcium chloride, causing the instant gelation of the droplet surface, due to the formation of calcium alginate. The obtained beads are freeze dried resulting in a porous structure, which aid in floating. The authors studied the behavior of radiolabeled



floating beads and compared with nonfloating beads in human volunteers using gamma scintigraphy. Prolonged gastric residence time of more than 5.5 h was observed for floating beads. The nonfloating beads had a shorter residence time with a mean onset emptying time of 1 hr³².

Floating microspheres

A controlled release system designed to increase its residence time in the stomach without contact with the mucosa was achieved through the preparation of floating microspheres. Techniques involved in their preparation include simple solvent evaporation, and solvent diffusion and evaporation. The drug release and better floating properties mainly depend on the type of polymer, plasticizer and the solvents employed for the preparation. Polymers, such as polycarbonate, Eudragit® S and cellulose acetate, are used in the preparation of hollow microspheres, and the drug release can be modified by optimizing the amount of polymer and the polymer plasticizer ratio³³.

c) Raft forming systems

The basic mechanism involved in the raft formation includes the formation of viscous cohesive gel in contact with gastric fluids, wherein each portion of the liquid swells forming a continuous layer called a raft. The raft floats because of the buoyancy created by the formation of CO₂ and act as a barrier to

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prevent the reflux of gastric Contents like HCl and enzymes into the esophagus. Usually, the system contains a gel forming agent and alkaline bicarbonates or carbonates responsible for the formation of to make the system less dense and float on the gastric fluids³⁴.

Reckitt and Colman Products Ltd. have come out with such formulation in the treatment of H.pylori infections of GIT.

ADVANTAGES OF FLOATING DOSAGE FORM

- (1) These systems are particularly advantageous for drugs that are specifically absorbed from stomach or the proximal part of the small intestine, e.g., riboflavin and furosemide.
- (2) The fluctuations in plasma drug concentration are minimized, and concentration dependent adverse effects that are associated with peak concentrations can be prevented. This feature is of special importance for drugs with a narrow therapeutic index.
- (3) The efficacy of the medicaments administered utilizing the sustained release principle of floating formulation has been found to be independent of the site of particular medicaments.
- (4) Complete absorption of the drug from the floating dosage form is expected even at the



alkaline pH of the intestine. The dissolution of the drug in gastric fluid occurs and then the dissolved drug is available for absorption in the small intestine after emptying of the stomach contents.

- (5) Poor absorption is expected when there is vigorous intestinal movement and a shorted transit time as might occur in certain type of diarrhea. Under such circumstances it may be advantageous to keep the drug in floating condition in stomach to get a relatively better response.
- (6) Drugs that have poor bioavailability because of site specific absorption from the upper part of the gastrointestinal tract are potential candidates to be formulated as floating drug delivery systems, thereby maximizing their absorption. A significant increase in the bioavailability of floating dosage forms (42.9%) could be achieved as compared with commercially available LASIX tablets (33.4%) and enteric coated LASIX long product (29.5%).

LIMITATIONS OF FLOATING DRUG DELIVERY SYSTEMS

- (1) A high level of fluid in the stomach is required for drug delivery to float and work efficiently.
- (2) Drugs which have stability and solubility problems in GIT are not suitable candidates for these types of systems.

(3) Drugs such as nifedipine, which under goes first pass metabolism may not be desirable for the preparation of these types of systems.

(4) Drugs which are irritant to Gastric mucosa are also not desirable.

(5) The drug substances that are unstable in the acidic environment of the stomach are not suitable candidates to be incorporated in the systems.

IN VITRO AND IN VIVO EVALUATION PARAMETERS OF STOMACH SPECIFIC FDDS

Different studies reported in the literature indicate that pharmaceutical dosage forms exhibiting gastric residence in vitro floating behavior show prolonged gastric residence in vivo. Although, in vitro floating behavior alone is not sufficient proof for efficient gastric retention so in vivo studies can provide definite proof that prolonged gastric residence is obtained.

1) Hardness, friability, assay, content uniformity (Tablets)

These tests are performed as per described in specified monographs.

2) Floating lag time and total floating time determination

The time between the introduction of the tablet into the medium and its rise to upper



one third of the dissolution vessel is termed as floating lag time and the time for which the dosage form floats is termed as the floating or flotation time. These tests are usually performed in simulated gastric fluid or 0.1 mole.lit⁻¹ HCl maintained at 37°C, by using USP dissolution apparatus containing 900 ml of 0.1 molar HCl as the dissolution medium³⁵.

3) Drug release

The test for in vitro drug release studies are usually carried out in simulated gastric and intestinal fluids maintained at 37°C. Dissolution tests are performed using the USP dissolution apparatus. Samples are withdrawn periodically from the dissolution medium, replaced with the same volume of fresh medium each time, and then analyzed for their drug contents after an appropriate dilution. Recent methodology as described in USP XXIII states that the dosage unit is allowed to sink to the bottom of the vessel before rotation of blade is started. A small, loose piece of non reactive material such as not more than a few turns of wire helix may be attached to the dosage units that would otherwise float. However, standard dissolution methods based on the USP or British Pharmacopoeia (BP) have been shown to be poor predictors of in vitro performance for floating dosage forms.

4) Drug loading, drug entrapment

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efficiency, particle size analysis, surface characterization, micromeritics studies and percentage yield (for floating microspheres and beads)

Drug loading is assessed by crushing accurately weighed sample of beads or microspheres in a mortar and added to the appropriate dissolution medium which is then centrifuged, filtered and analyzed by various analytical methods like spectrophotometry. The percentage drug loading is calculated by dividing the amount of drug in the sample by the weight of total beads or microspheres. The particle size and the size distribution of beads or microspheres are determined in the dry state using the optical microscopy method. The external and cross-sectional morphology (surface characterization) is done by scanning electron microscope (SEM). The measured weight of prepared microspheres was divided by total amount of all non-volatile components used for the preparation of microspheres, which will give the total percentage yield of floating microspheres^{36, 37}.

5) X-Ray/Gamma scintigraphy

For in vivo studies, X Ray/Gamma Scintigraphy is the main evaluation parameter for floating dosage form. In each experiment, the animals are allowed to fast overnight with free access to water, and a

**Table 1: Commercially available floating products**

Brand Name	Drug	Dosage form	Polymers used	Manufacturers
Cifran O.D	Ciprofloxacin	Tablet	Xanthan gum and sodium alginate	Ranbaxy
Liquid Gavison	Mixture of Alginates	Liquid	Alginates	GlaxoSmithKline
Madopar HBS	Levodopa and Benserazide	Capsule	HPMC	Roche
Glumetza	Metformin Hydrochloride	Tablet	HPMC	Depomed

radiograph is made just before the administration of the floating tablet to ensure the absence of radio opaque material. Visualization of dosage form by X ray is due to the inclusion of a radio opaque material. The formulation is administered by natural swallowing followed by 50 mL of water. The radiographic imaging is taken from each animal in a standing position, and the distance between the source of X rays and the animal should kept constant for all imaging, so that the tablet movement could be easily noticed. Gastric radiography was done at 30 min time intervals for a period of 5 h using an X ray machine.

Gamma scintigraphy is a technique whereby the transit of a dosage form through its intended site of delivery can be non invasively imaged in vivo via the judicious introduction of an appropriate short lived gamma emitting radioisotope. The inclusion of a γ emitting radionuclide in a formulation allows indirect external observation using a γ camera or scintiscanner. But the main drawback of γ scintigraphy are the associated ionizing radiation for the patient, www.pharmaerudition.org Nov. 2019, 9(3), 32-46

the limited topographic information, low resolution inherent to the technique and the complicated and expensive preparation of radiopharmaceutical^{28, 39}.

6) Pharmacokinetic studies

Pharmacokinetic studies include AUC (Area under Curve), C_{max} , and time to reach maximum plasma concentration (T_{max}) were estimated using a computer. Statistical analyses were performed using a Student t test with p , 0.05 as the minimal level of significance⁴⁰.

7) Specific Gravity

Displacement method is used to determine the specific gravity of floating system using benzene as a displacing medium¹⁸.

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