Pharmedico Publishers
International Journal of Pharmaceutical Science and Medicine
Volume 3, Issue 3 (2025): 105-115
DOI: 10.70199/IJPSM.3.3.105-115

REVIEW ARTICLE

ISSN: 2584-1610 (Online)

TARGETED AND CONTROLLED DRUG DELIVERY USING NANOSPONGES: EMERGING TRENDS IN RABEPRAZOLE-BASED ANTIULCER THERAPY

Awinish Kumar Shrivastaw*, Manju Makhija

School of Health & Allied Sciences, Career Point University, Kota, Rajasthan, India.

Article History
Received: 27 July 2025
Revised: 13 August 2025
Accepted: 28 August 2025
Published: 25 September 2025

Correspondence should be addressed to
Awinish Kumar Shrivastaw,
PhD. Research Scholar,
School of Health & Allied Sciences,
Career Point University, Kota,
Rajasthan, India.

Email-awinishpharma2017@gmail.com

ABSTRACT: Peptic ulcer disease (PUD) is a widespread gastrointestinal disorder caused by excessive gastric acid secretion, Helicobacter pylori infection, and prolonged use of nonsteroidal anti-inflammatory drugs. Although current pharmacological therapies have improved disease management, conventional drug delivery systems still present major limitations, including poor stability in acidic environments, rapid degradation, reduced oral bioavailability, and the requirement for frequent dosing. Rabeprazole is a commonly prescribed proton pump inhibitor that effectively suppresses gastric acid secretion and facilitates ulcer healing. However, its therapeutic efficiency is significantly compromised due to its acid-labile nature and short biological half-life. To address these limitations, advanced drug delivery strategies emphasizing targeted and controlled release have gained increasing attention. Nanosponges, a novel class of nanoporous, cross-linked polymeric carriers, have emerged as a promising platform for improving drug delivery performance. Their unique porous architecture enables efficient encapsulation of Rabeprazole, protecting it from acidic degradation while allowing sustained and controlled release of the drug over extended periods. Recent studies demonstrate that Rabeprazole-loaded nanosponges significantly enhance drug stability, improve bioavailability, prolong therapeutic action, and reduce dosing frequency. Furthermore, their potential for site-specific gastric delivery minimizes systemic exposure and associated adverse effects. This innovative system represents a significant advancement in antiulcer therapy. Future research focusing on large-scale production, clinical validation, and regulatory approval will be essential to fully translate nanosponge-based delivery systems into effective and reliable clinical applications.

Keywords: Rabeprazole, Nanosponges, Controlled drug delivery, Antiulcer therapy, Targeted delivery

I. INTRODUCTION

Peptic ulcer disease (PUD) is a common gastrointestinal disease that involves the occurrence of lesions of gastric or duodenal mucosa that results because of the disequilibrium between factors of aggression and the defense system of the mucosa. This is mainly caused by excessive secretion of the gastric acid, infection with Helicobacter pylori and long-term use of nonsteroidal anti-inflammatory drugs (NSAIDs) [1]. These agents interfere with the protective mucosal barrier causing inflammation and development of ulcers. Otherwise, PUD may lead to severe complications, including gastrointestinal bleeding, perforation, and gastric outlet obstruction, which may cause higher morbidity and health care burden across the globe [2]. The gastric acid is the key factor in the pathogenesis of ulcers and is primarily controlled by the enzyme H/K-ATPase (commonly called proton pump) located in the parietal cells of the stomach. Blockage of this enzyme is a proven method of decreasing the secretion of acid and promoting the healing of the ulcers. Rabeprazole is a proton pump inhibitor (PPI) that is commonly used, permanently blocking H+ / K +-ATPase and resulting in long-term gastric acid secretion. With its quick action and potency, Rabeprazole has emerged as a major medication in the treatment of PUD and other acid-peptic diseases [3].

Nevertheless, in spite of its treatment benefits, standard Rabeprazole preparations have numerous drawbacks. The drug is very acid-labile, and it quickly decays in the acidic gastrointestinal environment, which limits bioavailability. Moreover, its low biological half-life requires that it be dosed frequently, which can also affect patient compliance. Given the variability in drug absorption and the first-pass metabolism, there is additional variability in the therapeutic outcome [4].

Nanotechnology has brought a revolution in drug delivery in recent years with new systems that are used to prolong drug stability, targeting and controlled release. Nanosponges have been one of these promising nanoporous carriers, which are cross-linked polymeric materials that can be used to encapsulate both hydrophilic and lipophilic drugs. Their three-dimensional shape gives them high drug loading capacity, shields the drug against degradation and can release the drug in a sustained and site-specific manner. Thus, nanosponge-based systems of delivery appear to be a new and effective approach to address the shortcomings of the traditional Rabeprazole therapy and enhance its treatment effect in the treatment of antiulcers [5].

2. Literature Search Methodology

An extensive and methodical literature search was carried out to obtain the scientific information on the targeted and controlled delivery of Rabeprazole with the help of nanosponge-based systems. Several electronic databases such as PubMed, ScienceDirect, SpringerLink, and Google Scholar were thoroughly searched so that the published research articles, reviews, and experimental studies addressing the topic are widely covered [6].

Specific keywords and combination of these keywords were used as search strategy to retrieve the most relevant literature. The main keywords were: Rabeprazole nanosponges, targeted antiulcer delivery, controlled release proton pump inhibitors, nanotechnology in drugs delivery and nanosponge drug delivery system. To narrow down the search and enhance specificity of the results, Boolean operators like AND and OR were used. Besides, reference lists of the chosen articles were sifted manually to find more relevant studies [7].

Peer-reviewed articles describing nanotechnology-based drug delivery systems, especially nanosponge formulations of Rabeprazole or other proton pump inhibitors, were included as the inclusion criteria. *In vitro* and *in vivo* experiments that assessed the behavior of drug release, pharmacokinetics, therapeutic effect, and formulations formulation were taken into account to have a wholesome insight on the topic [8].

The exclusion criteria were non-peer-reviewed information, unpublished reports, conference abstracts without the text, and studies that lacked adequate methodological information. Articles that did not address directly nanosponge based delivery or antiulcer therapy were also filtered out [9].

Data collected were managed, tabulated and classified in a systematic way to ensure the data could easily be presented, the findings compared and the emerging trends in nanosponge based system of delivery of antiulcer drugs could be critically evaluated [10].

3. Overview of Rabeprazole in Antiulcer Therapy

3.1 Pharmacology

Rabeprazole is a benzimidazole derivative, which is substituted with the class of proton pump inhibitors (PPIs) that are widely used in managing peptic ulcer disease, gastroesophageal reflux disease (GERD) and other acid related disorders. It works by inhibiting the H +/K + -ATPase system of the gastric proton pump commonly found on the secretory surface of gastric parietal cells selectively and irreversibly. It is the last step in the secretion of gastric acid, which is catalyzed by this enzyme, which replaces the intracellular Hydrogen ion with the extracellular potassium ion [11].

Rabeprazole is a prodrug which is activated in the acidic environment of the secretory canaliculi of the parietal cells. After activation, it covalently binds to cysteine residues of the proton pump resulting in long-lasting inhibition of acid secretion (Table 1). This irreversible binding causes a long-term inhibition of gastric acid production, even after the drug has come out of the systemic circulation. Rabeprazole also has a comparatively fast action, which allows faster symptom relief and higher healing rates in ulcer patients, compared to other PPIs [12].

3.2 Limitations

Although Rabeprazole has clinical efficacy, there has been a number of limitations that relate to its performance as a therapeutic agent. Its acid-labile property is one of the greatest weaknesses and thus it is very vulnerable to acidic gastric environment, where it is likely to degrade before reaching its site of action. Such instability results in decreased drugs supply and impaired treatment results [13].

Also, the oral bioavailability of Rabeprazole is low and variable because of the following factors poor stability, intermittent absorption, and physicochemical characteristics. First-pass liver metabolism of the drug is also extensive, mainly through cytochrome P450 enzymes, which causes a significant decrease in the quantity of active drug in the systemic circulation. Moreover, it has a low biological half-life, which means that patients require repeated doses to sustain effective plasma levels, a feature that could impact patient compliance and subject them to dose variability [14].

3.3 Need for Advanced Delivery

The constraints relating to traditional Rabeprazole preparations further highlight the need to develop improved drug delivery platforms that could increase its stability, bioavailability, and therapeutic potential. Drug gastric acid resistance to maintain the pharmacological activity of the drug, gastric acid resistance is necessary before the drug enters the target site. Encapsulation methods have the ability to protect the drug against the extreme factors in the environment and avoid early degradation [15]. Controlled release systems also play a crucial role as they enable the drug to be released steadily over a long period of time to assure stable therapeutic concentrations and minimize frequent dosing. Not only does this increase patient compliance but also overall treatment outcome.

Table 1: Pharmacokinetic and Pharmacological Profile of Rabeprazole

Parameter	*Description*
Drug class	Proton pump inhibitor (PPI)
Chemical class	Substituted benzimidazole derivative
Mechanism of action	Irreversible inhibition of H^+/K^+-ATPase enzyme
Site of action	Gastric parietal cells
Therapeutic use	Peptic ulcer disease, GERD, Zollinger–Ellison syndrome
Dosage form	Tablets, delayed-release formulations
Route of administration	Oral
Bioavailability	Approximately 50–60% (variable)
Onset of action	Rapid onset compared to other PPIs
Half-life	~1–2 hours
Protein binding	~96–97% bound to plasma proteins
Metabolism	Hepatic metabolism via CYP450 enzymes

Moreover, targeted or site-specific delivery to gastric mucosa can achieve the maximum drug concentration at the site of action and reduce the systemic exposure and side effects. In this regard, nanotechnology-driven carriers, especially nanosponges, provide a viable solution. They are particularly useful in the delivery of Rabeprazole in the context of antiulcer therapy because they are unique porous structures, have high drug loading capacities, and can deliver the drug in a sustained and targeted release [16, 17].

4. Nanosponges: Structure and Characteristics

4.1 Definition

Nanosponges are a new category of nanostructured drug delivery systems which are nano-sized, highly porous, three-dimensional polymeric networks. The formation of these structures is achieved by cross-linking of polymers, leading to a sponge-like structure with many internal cavities and channels that can be used to entrap active pharmaceutical constituents [18]. Nanosponges have a high probability of absorbing the drug because they are nanoscale and have a high surface area, which increases the ability of the nanosponges to absorb both lipophilic and hydrophilic drugs, thereby increasing their application in drug delivery methods. Their most important strengths lie in being able to withstand environmental degradation of encapsulated drugs, like hydrolysis, oxidation, or pH-induced instability. Nanosponges are especially useful in the delivery of acid-labile drugs, such as Rabeprazole, in that the harsh acidic environment of the stomach can damage these drugs, whereas nanosponges can protect them and enhance their effectiveness [19].

4.2 Composition

The main components of nanosponges include biocompatible polymers and appropriate cross-linking agents which combine to create a structure of stable and porous network. Ethyl cellulose, polymethyl methacrylate, and cyclodextrins (particularly, 8-cyclodextrin), which is a very popular polymers due to its capacity to form inclusion complexes with drug molecules and increase solubility, are commonly used [20].

Diphenyl carbonate, diisocyanates or carbonyldiimidazole are cross-linkers that are used to bind polymer chains to create a rigid and stable structure of a nanosponge. The weight of polymer and cross linker greatly affect the physicochemical characteristics of the nanosponges, such as the pore size, surface area, mechanical strength, and the efficiency of the drug loading. Moreover, the preparation can be performed in the presence of surfactants and organic solvents that can be used to guarantee the generations of uniform particles, enhance dispersion, and stabilize the nanosponge system [21].

4.3 Key Properties

Nanosponges have a number of unique characteristics that predispose them to be very suitable in the high-tech drug delivery. This is because of their porous structure and large internal surface area which endows them with high drug loading capacity which enables them to easily encapsulate therapeutic agents [22].

They allow the constant and slow release of the drug by controlling the diffusion of drug molecules out of the nanosponge matrix with time. This will lead to long-term treatment and decreased frequency of dosing, thus enhancing patient compliance [23].

Moreover, nanosponges may greatly contribute to drug stability by preventing the destruction of encapsulated molecules by various environmental factors e.g. pH, temperature and enzyme activity. They are a promising and innovative platform in contemporary pharmaceutical sciences, especially in targeted antiulcer treatment due to their biocompatibility, low toxicity, and capability to enhance drug solubility and bioavailability (Figure 1) [24].

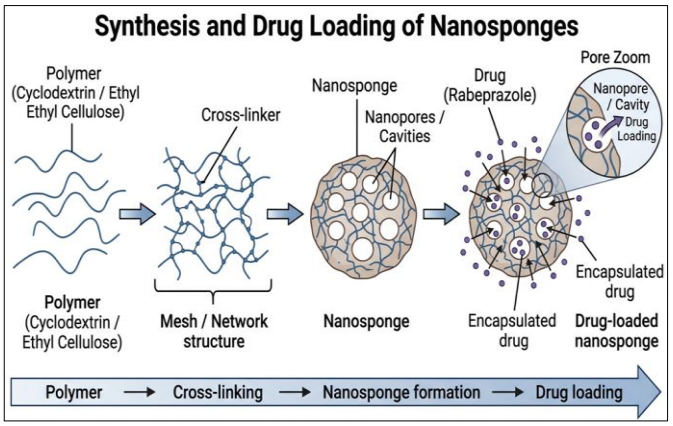

Figure 1: Structure and Formation of Drug-Loaded Nanosponges [25]

5. Preparation Methods of Nanosponges

There are a number of methods that are used to make nanosponges and each method affects the structure, porosity, particle size and the drug release profile of the end product. Selection of the type of preparation is based on the nature of the polymer, cross linking agent, solvent system and the physicochemical characteristics of the drug that is to be incorporated. In case of acid-labile drugs, like Rabeprazole, it is necessary to choose the suitable method of preparation that will guarantee against the degradation of the drug in the stomach as well as the release of the drug in a sustained and targeted manner [26].

5.1 Solvent Method

One of the most widespread techniques which are used in the preparation of nanosponges is the solvent method. Here, the polymer of choice (*e.g.*, ethyl cellulose or cyclodextrin) is dissolved in the appropriate organic solvent, e.g., dichloromethane or dimethylformamide. The polymer solution is then continued to stir under constant temperature and cross-linking agent is added to start the cross-linking reaction [27].

The reagent is left to react over a given time span in order to guarantee the development of a three-dimensional porous structure. Once it is completed, the mixture is cooled, and the formed nanosponges are filtered. The product is completely washed to eliminate unreacted chemicals and solvents and dried either under vacuum or controlled temperature. The technique offers excellent control of pore size, structural homogeneity and drug loading efficiency [28].

5.2 Ultrasound-Assisted Method

The ultrasound-assisted methodology is a sophisticated procedure that incorporates the use of ultrasonic energy in order to improve the development of nanosponges. In this process, the polymer and cross-linker are in direct contact and often with little or no solvent, and exposed to ultrasonic waves. The ultrasonic energy creates cavitation, which causes highly integrated mixing and effective cross-linking [29].

This technique has a number of benefits such as decreased reaction time, enhanced uniformity of particle size, and porosity. It is also found to be more environmentally friendly because of less solvent that is used. The resulting nanosponges are purified, filtered and dried to get them further characterized. The method is especially applicable to the creation of nanoscale particles that have high drug encapsulation efficiency [30].

5.3 Emulsion Solvent Diffusion Method

The emulsion solvent diffusion process is popular in the manufacture of drug-loaded nanosponges having a homogeneous distribution of particle size. The internal phase, in this method, is made by dissolving the polymer and drug in a volatile organic solvent. This stage is gradually added to an aqueous phase that includes a surfactant or stabilizer and stirred on continuing basis to create an oil-in-water emulsion.

Upon diffusion of the organic solvent into the aqueous solution, the polymer precipitates to give nanosponge particles that entrap the drug. The particles are then centrifuged or filtered, washed to get rid of excess surfactant and dried. This is a very useful approach towards high drug loading, controlled particle size and reproducible formulations [31].

Key Steps in Nanosponge Preparation

- **Polymer Selection:** The choice of polymer significantly affects the structural properties, drug compatibility, and release kinetics of nanosponges.
- **Cross-linking:** Chemical bonding between polymer chains creates a stable and porous nanosponge network. The degree of cross-linking determines pore size and drug release behavior.
- **Drug Loading:** The drug can be incorporated either during nanosponge formation or by post-loading methods, ensuring efficient encapsulation and minimal drug loss.
- **Drying and Characterization:** The prepared nanosponges are dried using appropriate techniques and evaluated for parameters such as particle size, morphology, surface charge, drug content, and in vitro release profile [32].

These preparation methods collectively enable the development of efficient nanosponge-based drug delivery systems with enhanced stability, controlled release, and improved therapeutic performance.

6. Mechanism of Controlled and Targeted Drug Release

Nanosponges are highly porous cross-linked polymeric nanocarriers that are capable of delivering drugs in a controlled site-specific manner. Several interdependent processes control their drug release mechanism, ensuring a long-lasting therapeutic effect and enhanced efficacy of acid-sensitive medications like Rabeprazole. These processes increase the stability of drugs, improve release kinetics and enhance site-of-action localization [33].

6.1 Drug Entrapment within Porous Structure

Encapsulation of drug molecules in the internal cavities of the porous network is the first step in the nanosponge-mediated delivery. These nanocavities serve as reservoirs in which drug molecules are physically adsorbed or form inclusion complexes or are weakly interacting via van der Waals force and hydrogen bonding. The large surface area and interconnected channels of the pores enable high drug loading and distribution [34].

This entrapment keeps the drug intact before it is lost due to acidic gastrointestinal tracts, enzymatic actions or other environmental conditions. With Rabeprazole, which is highly acid-labile, nanosponge encapsulation is essential to maintain chemical stability of the drug until it gets to its intended site of release [35].

6.2 Diffusion-Controlled Release

The diffusion-controlled release of drug through nanosponges is mainly governed by diffusion. When the nanosponge system is in contact with the biological fluids, the solvent molecules enter the porous structure, dissolving the drug contained within it. The medication subsequently spreads slowly out of the inner chambers to the outside world over a concentration gradient [36].

The diffusion rate depends on various factors such as the size of the pores, the extent of cross-linking, the composition of the polymer, and the interactions of the drug with the polymer. Increased level of cross-linking tends to reduce the rate of release, thus allowing the delivery of the drug to be extended. This prolonged release system aids in maintaining steady plasma drug levels, decreases dose rate and enhances adherence in patients [37].

6.3 pH-Responsive Behavior

Nanosponges may be designed to be pH-sensitive, thus, becoming very useful in gastrointestinal drug delivery. The nanosponge matrix is relatively stable in the highly acidic environment of the stomach, thus ensuring that the encapsulated drug is not degraded. When the system is subjected to a change of pH along the gastrointestinal tract, the polymer network can either swell, relax or change structure [38].

This pH-dependent reaction enables the release of drugs in a controlled manner in particular positions where they will be better absorbed. In the case of Rabeprazole, this kind of mechanism helps to ensure that the medicine will not be destroyed when exposed to acid, and will be released in a controlled manner, which increases its therapeutic efficacy [39].

6.4 Enhanced Gastric Retention

Nanosponges also help in increased gastric retention, which is most advantageous to drugs that are meant to act locally in the stomach. The mucosal surface attributes and their size (nano) enable them to interact better with the gastric mucosa and result in extended retention time in the gastric area.

Such prolonged retention results in sustained and localized release of drug, which sustains effective drug concentration in the ulcerative site. Also, the long periods of gastric residence will allow for a continued inhibition of acid secretion, hence, enhancing ulcer healing. Increased retention and eventual controlled release translate to better therapeutic effects and fewer systemic side effects [40].

In sum, combining a synergistic approach of the nanosponges as a drug entrapment system, diffusion-controlled release, pH responsiveness, and extended gastric retention, the nanosponges will be an effective and novel system of targeted and controlled drug delivery in the contemporary antiulcer treatment (Figure 2).

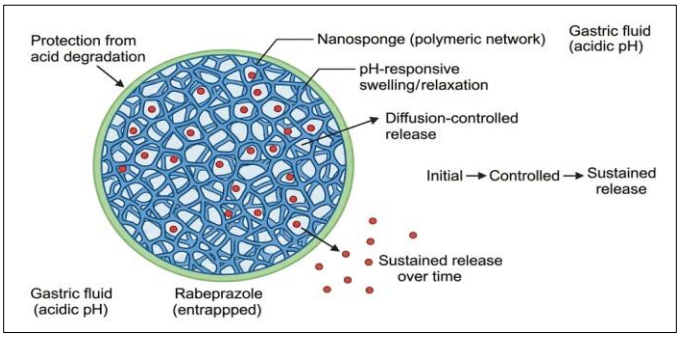

Figure 2: Mechanism of Controlled Release of Rabeprazole from Nanosponges [41]

7. Evaluation and Characterization of Nanosponges

The successful development of nanosponge-based drug delivery systems requires comprehensive evaluation and characterization to ensure their stability, efficiency, and reproducibility. These parameters are essential for optimizing formulation performance, particularly for delivering acid-labile drugs such as Rabeprazole in a controlled and targeted manner (Table 2) [42].

7.1 Particle Size Analysis

Particle size is a crucial parameter, which determines the drug loading, release characteristics, stability and bioavailability. It is usually quantified by either dynamic light scattering (DLS) or laser diffraction. A smaller particle size gives more surface area, which increases dissolution and absorption of drugs, and a consistent distribution of the sizes of particles provides stability and consistency of the formulation. Polydispersity index (PDI) is also determined to determine the homogeneity of nanosponge particles [43].

7.2 Zeta Potential

The Zeta potential is a measure of the surface charge of nanosponge particles, and a significant measure of colloidal stability. It is determined by electrophoretic light scattering. When zeta potential is high (positive or negative) its absolute value is large; this shows that there is a lot of repulsive electrostatic force between particles and hence the particles do not form aggregates, making them more stable during storage and use. The systems of nanosponge that are stable are those with a zeta potential of more than ± 20 mV [44].

7.3 Drug Entrapment Efficiency

The efficacy of the entrapment is the percentage of drug that has been incorporated in the nanosponge matrix successfully. It is identified by centrifugation or filtration of the unentrapped drug and the formulation and quantitative analysis with UV-visible spectroscopy or high-performance liquid chromatography (HPLC). High entrapment efficiency implies a good loading of the drug and good formulation design which is essential in the production of a sustained therapeutic effect [45].

7.4 SEM/TEM Imaging

Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM) are used to examine the surface morphology, shape, and internal structure of nanosponges. SEM provides detailed images of surface texture and porosity, while TEM offers insights into internal architecture at higher resolution. These imaging techniques confirm the formation of nanosponge structures and help correlate morphology with drug loading and release characteristics [46].

7.5 *In Vitro* Drug Release Studies

In vitro drug release studies are conducted to evaluate the release profile of the drug from nanosponges under simulated physiological conditions. These studies are typically performed using dissolution apparatus in appropriate buffer solutions at controlled pH and temperature. The amount of

drug released at specific time intervals is measured using analytical techniques such as UV spectroscopy or HPLC. The release data help determine the kinetics and mechanism of drug release, confirming whether the system provides sustained and controlled delivery [47].

Table 2: Evaluation Parameters of Rabeprazole Nanosponges [48]

Parameter	*Method/Technique*	*Significance*
Particle size	Dynamic Light Scattering (DLS)	Determines size distribution and influences drug release
Polydispersity Index (PDI)	DLS analysis	Indicates uniformity and homogeneity of particles
Zeta potential	Electrophoretic light scattering	Evaluates surface charge and stability of formulation
Surface morphology	Scanning Electron Microscopy (SEM)	Assesses shape, surface texture, and porosity
Internal structure	Transmission Electron Microscopy (TEM)	Provides insight into internal architecture
Drug entrapment efficiency	UV spectroscopy / HPLC	Measures percentage of drug encapsulated
Drug loading capacity	Analytical quantification	Determines amount of drug per unit carrier
In vitro drug release	Dissolution apparatus	Evaluates release profile and kinetics
Fourier Transform Infrared (FTIR) analysis	FTIR spectroscopy	Identifies drug–polymer interactions
Differential Scanning Calorimetry (DSC)	Thermal analysis	Determines thermal behavior and compatibility
X-ray diffraction (XRD)	XRD analysis	Assesses crystallinity and amorphous nature
Surface area analysis	BET method	Determines porosity and surface characteristics

8. Therapeutic Advantages in Antiulcer Therapy

Nanosponge-based drug delivery systems have become a promising methodology to optimize the application of antiulcer drugs in terms of their therapeutic efficacy by overcoming the severe shortcomings of traditional preparations. Their special porous structure, high surface area and capacity to offer controlled release have an enormous contribution to the pharmacokinetic and pharmacodynamic characteristics of the acid-labile compounds like Rabeprazole. All these benefits lead to improved patient outcomes and improved management of ulcers [49].

8.1 Protection from Acidic Degradation

The major problems in oral delivery of Rabeprazole are its instability at acidic gastric environment. Nanosponges are able to entrap the drug in their internal diameters and provide a shield against gastric acid. This protection prevents degradation that occurs too soon and guarantees that the percentage of drug that is retained to reach the site of action is higher. This causes a great deal of improvement in drug stability, resulting in increased therapeutic efficiency [50].

8.2 Sustained Drug Release

Nanosponges facilitate a slow and controlled release of the drug contained within it during an extended period. Diffusion and matrix relaxation processes slowly release the drug out of the nanosponge matrix to ensure constant plasma concentrations. This long-acting release is especially advantageous in antiulcer therapy where uninterrupted inhibition of gastric acid is necessary to promote healing and prevent ulcer recurrence [51].

8.3 Reduced Dosing Frequency

The sustained release characteristics of nanosponge formulations reduce the need for frequent drug administration. Conventional Rabeprazole therapy often requires repeated dosing due to its short half-life, whereas nanosponge-based systems can maintain therapeutic levels for longer periods. This reduction in dosing frequency simplifies treatment regimens and minimizes the chances of missed doses [52].

8.4 Improved Patient Compliance

Simplified dosing schedules and consistent therapeutic outcomes contribute to improved patient compliance. Patients are more likely to adhere to treatment when medication frequency is reduced and effectiveness is enhanced. Improved compliance is crucial in chronic conditions like peptic ulcer disease, as it directly impacts the success of therapy and reduces the risk of complications or relapse [53].

8.5 Enhanced Therapeutic Efficacy

The integration of protection, sustained release, and targeted delivery leads to a significant improvement in overall therapeutic efficacy. Nanosponges enhance the bioavailability of Rabeprazole by minimizing degradation and improving drug absorption. Additionally, their ability to localize drug release in the gastric region ensures higher drug concentration at the site of action while reducing systemic exposure and side effects [54].

9. Recent Advances and Research Trends

Recent years have witnessed significant progress in the development of nanosponge-based drug delivery systems, driven by the need to enhance the therapeutic efficiency of acid-labile drugs such as Rabeprazole. Ongoing research focuses on improving structural design, targeting ability, and multifunctionality of nanosponges to achieve more precise and effective antiulcer therapy [55].

9.1 Cyclodextrin-Based Nanosponges

Nanosponges made of cyclodextrin and especially of β-cyclodextrin have received a significant amount of attention because they have a better capacity to form inclusion complexes with drug molecules. The nanosponges have a porous structure of hydrophobic cavities and hydrophilic outer surfaces and are effective in encapsulating poorly soluble drugs.

Cyclodextrin-based nanosponges, in the case of Rabeprazole, facilitate solubility, acidic degradation resistance and bioavailability of the drug. They also provide improved control over kinetics of drug release and have a high level of biocompatibility and are therefore very suitable in the use of oral drug delivery [56].

9.2 Hybrid Nanosponge Systems

Hybrid nanosponges are a progressive form of nanosponges engineering into which nanocarriers or other functional materials are incorporated to improve their functionality. Such systems can also include polymers, lipids, or inorganic nanoparticles to enhance drug loading capacity, stability, and effectiveness of tracking the target.

Multifunctional properties (pH responsiveness, mucoadhesion or stimuli-triggered release) can be designed into hybrid systems. These modifications enable the delivery of the drugs to be more precisely controlled, and these are especially useful when complex therapeutic needs in the treatment of antiulcers are involved [57].

9.3 Targeted Gastric Delivery Systems

One of the specialization areas of research is targeted gastric delivery, which aims to enhance the concentration of drugs in the ulceration location. Mucoadhesive properties may be used to adjust nanosponge systems to increase gastric retention or particle size and density can be adjusted.

These selective systems guarantee extended retention of time in the stomach, which enables constant discharge of Rabeprazole at the point of action. Such localization of delivery enhances the efficacy of the therapy, minimizes the side effects systemically and leads to better overall treatment outcomes [58].

9.4 Combination Therapies

The other trend is the utilization of nanosponge-delivered combination therapies, where Rabeprazole is co-delivered with other therapeutic agents like antibiotics (to eradicate Helicobacter pylori), antioxidants or anti-inflammatory agents. The strategy allows acting synergistically, considering a variety of factors that contribute to the pathogenesis of ulcers.

Nanosponges can be loaded with mixtures of various drugs in order to coordinate and regulate their release and enhance treatment efficacy and reduce the complexity of dosing. This approach has massive potential of holistic management of peptic ulcer disease (Table 3) [59].

10. Limitations and Challenges

Despite the promising potential of nanosponge-based drug delivery systems in improving the therapeutic performance of Rabeprazole, several limitations and challenges must be addressed before their successful translation into clinical and commercial applications. These challenges primarily relate to manufacturing, consistency, regulatory approval, and clinical validation [61].

Table 3: Recent Studies on Rabeprazole Nanosponges [60]

Study Type	Polymer Used	Method	Key Findings
In vitro study	Ethyl cellulose	Solvent method	Sustained drug release up to 24 hours
In vitro study	β-cyclodextrin	Cross-linking method	Improved encapsulation and stability
In vivo study (rats)	Cyclodextrin nanosponges	Oral administration	Enhanced bioavailability and ulcer healing
Formulation study	Ethyl cellulose nanosponges	Emulsion solvent diffusion	Uniform particle size and high entrapment
Comparative study	Conventional vs nanosponge	Dissolution study	Prolonged release compared to standard
Stability study	Cyclodextrin nanosponges	Accelerated testing	Increased resistance to acid degradation
Release kinetics study	Polymer-based nanosponges	Dissolution testing	Follows diffusion-controlled release
Particle size analysis	Ethyl cellulose system	DLS method	Nanoscale uniform particle distribution
Encapsulation study	β-cyclodextrin nanosponges	Cross-linking reaction	High entrapment efficiency (>80%)
Hybrid system study	Polymer-lipid nanosponges	Modified method	Improved targeting and sustained release
Mucoadhesive study	Surface-modified nanosponges	Functionalization technique	Increased gastric retention time
Combination therapy study	Rabeprazole + antibiotic	Nanosponge system	Synergistic antiulcer effect

10.1 Scale-Up Issues

The inability to scale up the production of nanosponge technology to the industrial scale is one of the greatest challenges of the technology. Various preparation techniques, including solvent-based techniques or ultrasound-based techniques, are best suited to small-scale production and might not readily scale to large-scale production. Such aspects as particle size control, cross-linking consistency, solvent removal, and batch consistency are further complicated during scale-up. Moreover, the challenge of being cost-effective and efficient in processes and at the same time maintaining quality of the product is another major challenge to pharmaceutical industries [62].

10.2 Reproducibility

Reproducibility is an important aspect in the development of pharmaceutical formulations. The nanosponge properties (particle size, porosity, and drug loading efficiency) can be inconsistent due to differences in preparation conditions, which include polymer-to-cross-linker ratio, temperature, stirring speed, and solvent system. This variability can lead to unpredictable profiles of drug release and therapeutic effects. The standardization of preparation methods is also a critical requirement to ensure that the regulatory approval and clinical reliability depend on batch-to-batch consistency [63].

10.3 Limited Clinical Data

Even though various *in vitro* and *in vivo* studies have shown the efficiency of the nanosponge-based delivery systems, no clinical evidence has been collected that can substantiate the popular use of nanosponge-based delivery systems in humans. All studies are at preclinical phase, and proper clinical trials should be conducted to determine safety, effectiveness, pharmacokinetics and outcomes in the long-run. These promising systems are hard to be translated into approved therapeutic products without strong clinical evidence [64].

10.4 Regulatory Concerns

Nanotechnology-based drug delivery systems are very complex in structure and operation and therefore, they are very difficult to gain regulatory approval. Regulatory guidelines are not clearly outlined that are specifically designed to be applied to nanosponge formulations. Problems like the standard of characterization, toxicity tests, long-term safety, and environmental effects need to be addressed completely. Regulatory bodies demand a complete information about quality, safety, and efficacy which can extend the approval procedure and raise the costs of development [65].

11. Future Perspectives

The field of nanosponge-based drug delivery is rapidly evolving and holds significant promise for transforming the management of peptic ulcer disease. With continued advancements in nanotechnology, future research is expected to focus on improving targeting efficiency, enhancing therapeutic precision, and facilitating clinical translation of nanosponge systems for drugs such as Rabeprazole [66].

11.1 Targeted Gastric Delivery Systems

Future developments are likely to emphasize the design of nanosponge systems capable of precise targeting within the gastric environment. Strategies such as mucoadhesive surface modification, ligand-mediated targeting, and floating delivery systems can enhance gastric retention and localization at the ulcer site. These targeted systems will ensure higher drug concentration at the site of action, leading to improved therapeutic efficacy while minimizing systemic exposure and side effects [67].

11.2 Smart Nanosponges (Stimuli-Responsive Systems)

An innovative type of drug delivery is the development of smart or stimulus-responsive nanosponges. Such systems may be designed to react to certain physiological conditions like pH, temperature, enzymes or redox situations. As an example, pH-responsive nanosponges can be kept stable in the acidic gastric environment and discharge the drug when the pH is changed. These intelligent systems provide accurate control of drug discharge, allowing on-demand therapy and better clinical results [68].

11.3 Clinical Trials for Validation

Although nanosponge-based formulations have shown promising preclinical outcomes, clinical trials need to be done on a large scale to confirm the safety, effectiveness and therapeutic efficacy of the nanosponge-based formulations. The proposed research needs to be followed by well-designed randomized clinical studies to assess the pharmacokinetics, bioavailability, long term safety and patient outcomes. A crucial step in achieving regulatory acceptance and making nanosponge systems a reliable treatment choice in the context of antiulcer will be clinical validation [69].

11.4 Commercial Formulation Development

For successful translation into the pharmaceutical market, efforts must be directed toward the development of scalable, cost-effective, and stable nanosponge formulations. Optimization of manufacturing processes, quality control standards, and packaging will be essential for commercialization. Collaboration between academic researchers, pharmaceutical industries, and regulatory agencies will play a key role in accelerating product development and approval [70].

12. Conclusion

Nanosponge-based drug delivery systems represent a significant advancement in the field of antiulcer therapy, particularly in improving the therapeutic performance of Rabeprazole. Their unique porous architecture and ability to encapsulate drugs effectively address the major limitations associated with conventional formulations, such as poor stability in acidic environments and rapid degradation.

By providing controlled and sustained drug release, nanosponges maintain consistent therapeutic drug levels over extended periods, reducing the need for frequent dosing. This not only enhances patient convenience but also improves overall treatment adherence. Furthermore, their capability for targeted delivery, especially within the gastric region, ensures higher drug concentration at the site of action, thereby increasing therapeutic efficacy while minimizing systemic exposure. In addition, nanosponge-based systems contribute to the reduction of side effects by preventing dose fluctuations and limiting unnecessary drug distribution to non-target tissues. Their biocompatibility, stability, and versatility make them an attractive platform for advanced drug delivery applications.

Overall, nanosponges offer a promising and innovative approach for optimizing Rabeprazole therapy in peptic ulcer disease. With continued research, clinical validation, and advancements in large-scale production, nanosponge-based formulations have the potential to become a key component in next-generation antiulcer drug delivery systems, improving both therapeutic outcomes and patient quality of life.

ACKNOWLEDGEMENT: Author are thankful to his supervisor and co-supervisor for their valuable guidance throughout this study.

CONFLICT OF INTEREST: Nil

REFERENCES:

1. Srivastav Y, Kumar V, Srivastava Y, Kumar M. Peptic ulcer disease (PUD), diagnosis, and current medication-based management options: schematic overview. Journal of Advances in Medical and Pharmaceutical Sciences. 2023 Dec 2;25(11):14-27.
2. Arshad SA, Murphy P, Gould JC. Management of perforated peptic ulcer: a review. JAMA surgery. 2025 Apr;160(4):450-4.
3. Pandey A, Saraswat N, Wal P, Pal RS, Wal A, Maurya D. A detailed review on: recent advances, pathophysiological studies and mechanism of peptic ulcer. Research journal of pharmacology and pharmacodynamics. 2019 Oct 1;11(4):165-70.
4. Srebro J, Brniak W, Mendyk A. Formulation of dosage forms with proton pump inhibitors: state of the art, challenges and future perspectives. Pharmaceutics. 2022 Sep 25;14(10):2043.
5. Shringirishi M, Prajapati SK, Mahor A, Alok S, Yadav P, Verma A. Nanosponges: a potential nanocarrier for novel drug delivery-a review. Asian pacific journal of tropical disease. 2014 Sep 1;4:S519-26.
6. Ramu S, Ram Kumar C, Sujala DP, Anwar K, Sampath AG, Ravindra Babu M, Palakurthi Y. A Prospective Review on Novel Strategies for Preparation and Evaluation of Nanosponge Tablets. European Chemical Bulletin. 2023;12(5):2428-96.
7. Mujtaba SH, Arshad R, Aman W, Barkat K, Malik A, Fatima A, Khan SA, Sadia H, e Maryam G, Moafian Z, Rahdar A. Innovative self nano-Emulsifying drug delivery systems for peptic ulcer therapy: a review. Particle & Particle Systems Characterization. 2025 Jan;42(1):2400070.
8. Kamankesh M, Yadegar A, Llopis-Lorente A, Liu C, Haririan I, Aghdaei HA, Shokrgozar MA, Zali MR, Miri AH, Rad-Malekshahi M, Hamblin MR. Future nanotechnology-based strategies for improved management of Helicobacter pylori infection. Small. 2024 Jan;20(3):2302532.
9. O'Kelly F, Fernandez N, Koyle MA. Predatory publishing or a lack of peer review transparency? a contemporary analysis of indexed open and non-open access articles in paediatric urology. Journal of pediatric urology. 2019 Apr 1;15(2):159-e1.
10. Vankudre S, Shirkoli N, Hawaldar R, Shetti H. Enhanced delivery of dacarbazine using nanosponge loaded hydrogel for targeted melanoma treatment: formulation, statistical optimization and pre-clinical evaluation. Journal of Pharmaceutical Innovation. 2025 Feb;20(1):27.
11. Pace F, Pallotta S, Casalini S, Porro GB. A review of rabeprazole in the treatment of acid-related diseases. Therapeutics and clinical risk management. 2007 Jun 30;3(3):363-79.
12. Dadabhai A, Friedenberg FK. Rabeprazole: a pharmacologic and clinical review for acid-related disorders. Expert Opinion on Drug Safety. 2009 Jan 1;8(1):119-26.
13. Luisetto M, Almukthar N, Edbey K, Mashori GR, Cabianca L, Latyshev O. 1*, ACIDO LABILE OR GASTRO IRRITANT APIs AND ENTERIC RELEASE IN GALENIC PRACTICE: AN OVERVIEW. Digestive System and Hepatobiliary Diseases. 2024;1(1).
14. Almazroo OA, Miah MK, Venkataramanan R. Drug metabolism in the liver. Clinics in liver disease. 2017 Feb 1;21(1):1-20.
15. Bhandare A, Nannor KM. Bioavailability in drug design and development: A comprehensive review. World Journal of Pharmaceutical Research. 2024 Jul 5;13(17):145-68.
16. SAHOO UK, VIDYACHARAN S, KAYAL P, JAWAHAR N. NANOTECHNOLOGY-DRIVEN INNOVATIONS IN HYPERTENSION MANAGEMENT: FORMULATION STRATEGIES, CHALLENGES, AND FUTURE DIRECTIONS. NANOTECHNOLOGY. 2025;18(4).
17. Horai Y, Kimura M, Furuie H, Matsuguma K, Irie S, Koga Y, Nagahama T, Murakami M, Matsui T, Yao T, Urae A. Pharmacodynamic effects and kinetic disposition of rabeprazole in relation to CYP2C19 genotypes. Alimentary pharmacology & therapeutics. 2001 Jun 12;15(6):793-803.
18. Mane PT, Wakure BS, Wakte PS. Cyclodextrin based nanosponges: a multidimensional drug delivery system and its biomedical applications. Current drug delivery. 2021 Dec 1;18(10):1467-93.
19. Tejashri G, Amrita B, Darshana J. Cyclodextrin based nanosponges for pharmaceutical use: A review. Acta pharmaceutica. 2013 Sep 30;63(3):335-58.
20. Al-kasmi B, Alsirawan MB, Bashimam M, El-zein H. Pharmaceutics and Pharmaceutical Technology, Damascus, Syria b Center for Pharmaceutical Engineering Science, Bradford, United Kingdom.
21. Shaikh RG, Mane RB. EXPLORING BETA-CYCLODEXTRIN NANOSPONGES AS MULTIDIMENSIONAL DRUG DELIVERY SYSTEMS: SYNTHESIS, PROPERTIES, BIOMEDICAL APPLICATIONS, AND RECENT PATENTS. World. 2026;5(2).
22. Patil M, Mehta DS, Guvva S. Future impact of nanotechnology on medicine and dentistry. Journal of Indian society of periodontology. 2008 May 1;12(2):34-40.
23. Tiwari K, Bhattacharya S. The ascension of nanosponges as a drug delivery carrier: preparation, characterization, and applications. Journal of Materials Science: Materials in Medicine. 2022 Mar;33(3):28.
24. Pyrak B, Rogacka-Pyrak K, Gubica T, Szeleszczuk Ł. Exploring cyclodextrin-based nanosponges as drug delivery systems: Understanding the physicochemical factors influencing drug loading and release kinetics. International journal of molecular sciences. 2024 Mar 20;25(6):3527.
25. Swaminathan S, Vavia PR, Trotta F, Cavalli R, Tumbiolo S, Bertinetti L, Coluccia S. Structural evidence of differential forms of nanosponges of beta-cyclodextrin and its effect on solubilization of a model drug. Journal of inclusion phenomena and macrocyclic chemistry. 2013 Jun;76(1):201-11.
26. Salman AH, Al-Gawhari FJ, Al-kinani KK. The effect of formulation and process variables on prepared etoricoxib Nanosponges. Journal of Advanced Pharmacy Education & Research. 2021 Apr;11(2):83.
27. Liebert T. Cellulose solvents–remarkable history, bright future. InCellulose solvents: for analysis, shaping and chemical modification 2010 (pp. 3-54). American Chemical Society.

28. Ghurghure SM, Pathan MS, Surwase PR. Nanosponges: A novel approach for targeted drug delivery system. Int. J. Chem. Studies. 2018 Nov;2(2).
29. Wadhwa P, Vij M, Dand N. Wave-assisted techniques, a greener and quicker alternative to synthesis of cyclodextrin-based nanosponges: A review. Recent patents on nanotechnology. 2024 Jun 1;18(2):207-19.
30. Valtchev V, Tosheva L. Porous nanosized particles: preparation, properties, and applications. Chemical reviews. 2013 Aug 14;113(8):6734-60.
31. Aneja P, Guleria R, Dahiya DP. Targeted drug delivery with nanosponges and nanocrystals: innovations, formulation strategies, and applications. Assay and drug development technologies. 2025 Oct;23(7):337-66.
32. Dini E, Alexandridou S, Kiparissides C. Synthesis and characterization of cross-linked chitosan microspheres for drug delivery applications. Journal of microencapsulation. 2003 Jan 1;20(3):375-85.
33. Trotta F, Zanetti M, Cavalli R. Cyclodextrin-based nanosponges as drug carriers. Beilstein journal of organic chemistry. 2012 Nov 29;8(1):2091-9.
34. Sarma S, Das AK, Khatiwara D, Bordoloi C, Kumar Deka M, Ansary A, Sahariah BJ. Nanosponge-Induced Amorphization for Controlled Transdermal Delivery of Febuxostat. Available at SSRN 6503802.
35. Mehetre GD, Cheke RS, Shrikhande VN. Formulation and in-vitro evaluation of enteric coated tablet incorporating rabeprazole. J. Drug Deliv. Ther. 2020 Mar 2;10:50-7.
36. Verma S, Preeti K, Rana AS, Sharma SK. Nanosponges for Chemosensors and Biosensors: Next Generation Functional Materials. Chemistry–An Asian Journal. 2025 Dec;20(24):e00876.
37. Khan S, Ranjha NM. Effect of degree of cross-linking on swelling and on drug release of low viscous chitosan/poly (vinyl alcohol) hydrogels. Polymer bulletin. 2014 Aug;71(8):2133-58.
38. Kerilos IE, EL-Sawy HS, Elyazid SK, Ibrahim MA. Nanosponge for enhancing solubility and bioavailability of oral drugs. Int J App Pharm. 2024;16(1):9-17.
39. Zhu YJ, Chen F. pH-responsive drug-delivery systems. Chemistry–an asian journal. 2015 Feb;10(2):284-305.
40. Sachs G, Shin JM, Hunt R. Novel approaches to inhibition of gastric acid secretion. Current gastroenterology reports. 2010 Dec;12(6):437-47.
41. Samineni R, Choudhary RK, Sujala DP, Khan A, Gouru SA, Babu MR, Yanadaiah P. A Prospective Review on Novel Strategies for Preparation and Evaluation of Nanosponge Tablets.
42. Mahalekshmi V, Balakrishnan N, Parthasarathy V. Recent advancement of nanosponges in pharmaceutical formulation for drug delivery systems. Journal of Applied Pharmaceutical Science. 2023 Aug 4;13(8):084-100.
43. Jain AK, Thareja S. In vitro and in vivo characterization of pharmaceutical nanocarriers used for drug delivery. Artificial cells, nanomedicine, and biotechnology. 2019 Dec 4;47(1):524-39.
44. Deshmukh K, Tanwar YS, Sharma S, Shende P, Cavalli R. Functionalized nanosponges for controlled antibacterial and antihypocalcemic actions. Biomedicine & Pharmacotherapy. 2016 Dec 1;84:485-94.
45. Tasnim S. Quantitative Analytical Validation of Herbal Drug Formulations Using UPLC And UV-Visible Spectroscopy: Accuracy, Precision, And Stability Assessment. ASRC Procedia: Global Perspectives in Science and Scholarship. 2023 May 29;3(1):01-36.
46. Ansari KA, Vavia PR, Trotta F, Cavalli R. Cyclodextrin-based nanosponges for delivery of resveratrol: in vitro characterisation, stability, cytotoxicity and permeation study. Aaps Pharmscitech. 2011 Mar;12(1):279-86.
47. Sheng JJ, McNamara DP, Amidon GL. Toward an in vivo dissolution methodology: a comparison of phosphate and bicarbonate buffers. Molecular pharmaceutics. 2009 Feb 2;6(1):29-39.
48. Gharge V, Gadhe A, Mohite V, Jadhav BG, Dighe V, Bhange S, Kakade S. Stability Indicating RP-HPLC Method for the Estimation of Impurities in Esomeprazole Gastro-Resistant Tablets by AQbD Approach. BIO Integration. 2024 Jul 1;5(1):988.
49. Das D, Afnan T, Chhetri P, Dutta Chakraborty D, Chakraborty P. An outlook towards nano-sponges: a unique drug delivery system and its application in drug delivery. Current Drug Delivery. 2023 Aug 1;20(7):884-903.
50. Setia A, Challa RR, Vallamkonda B, Viswanadh MK, Muthu MS. Clinical implications of proton pump inhibitors and vonoprazan micro/nano drug delivery systems for gastric acid-related disorders and imaging. Nanotheranostics. 2024 Sep 30;8(4):535.
51. Maggioni D, Galli M, Donghi D, D'Alfonso G, Manfredi A, Lascialfari A, Arosio P, D'Alfonso L, Cavalli R, Ranucci E, Ferruti P. Transition metal complexes of purpose--tailored biocompatible and biodegradable polymers for imaging and therapy.
52. Alapati S, Ray SK. Controlling Biogenesis and Engineering of Exosomes to Inhibit Growth and Promote Death in Glioblastoma Multiforme. Brain Sciences. 2026 Jan 25;16(2):130.
53. Ingersoll KS, Cohen J. The impact of medication regimen factors on adherence to chronic treatment: a review of literature. Journal of behavioral medicine. 2008 Jun;31(3):213-24.
54. Gad S, Hanna P, Ibrahem H, Mortagi Y. Surfactants' Role in Nanovesicles Drug Delivery System. Records of Pharmaceutical and Biomedical Sciences. 2023 Jan 1;7(3):140-9.
55. Garg A, Lai WC, Chopra H, Agrawal R, Singh T, Chaudhary R, Dubey BN. Nanosponge: A promising and intriguing strategy in medical and pharmaceutical Science. Heliyon. 2024 Jan 15;10(1).
56. Osmani RA, Kulkarni P, Manjunatha S, Gowda V, Hani U, Vaghela R, Bhosale R. Cyclodextrin nanosponges in drug delivery and nanotherapeutics. InEnvironmental Nanotechnology: Volume 1 2018 May 16 (pp. 279-342). Cham: Springer International Publishing.
57. Shishir MR, Gowd V, Suo H, Wang M, Wang Q, Chen F, Cheng KW. Advances in smart delivery of food bioactive compounds using stimuli-responsive carriers: Responsive mechanism, contemporary challenges, and prospects. Comprehensive Reviews in Food Science and Food Safety. 2021 Nov;20(6):5449-88.
58. Rettura F, Bronzini F, Campigotto M, Lambiase C, Pancetti A, Berti G, Marchi S, de Bortoli N, Zerbib F, Savarino E, Bellini M. Refractory gastroesophageal reflux disease: a management update. Frontiers in medicine. 2021 Nov 1;8:765061.
59. Moin A, Roohi NF, Rizvi SM, Ashraf SA, Siddiqui AJ, Patel M, Ahmed SM, Gowda DV, Adnan M. Design and formulation of polymeric nanosponge tablets with enhanced solubility for combination therapy. RSC advances. 2020;10(57):34869-84.

60. Fatma ID, Kartika Y, Ulfah RR, Rinaldi MD, Pratama R, Pahlevi MR. Formulasi dan Evaluasi Tablet Pelepasan Tertunda dan Pelepasan Terkontrol. Majalah Farmasetika. 2024 Sep 30;9(5):472-88.
61. Primorac D, Bach-Rojecky L, Vađunec D, Juginović A, Žunić K, Matišić V, Skelin A, Arsov B, Boban L, Erceg D, Ivkošić IE. Pharmacogenomics at the center of precision medicine: challenges and perspective in an era of Big Data. Pharmacogenomics. 2020 Jan 1;21(2):141-56.
62. Ahmed RZ, Patil G, Zaheer Z. Nanosponges–a completely new nano-horizon: pharmaceutical applications and recent advances. Drug development and industrial pharmacy. 2013 Sep 1;39(9):1263-72.
63. Gaber DA, Radwan MA, Alzughaibi DA, Alail JA, Aljumah RS, Aloqla RM, Alkhalifah SA, Abdoun SA. Formulation and evaluation of Piroxicam nanosponge for improved internal solubility and analgesic activity. Drug delivery. 2023 Dec 31;30(1):2174208.
64. Syed SM, Sowmya T, Koteswari P. Topical Delivery of Terbinafine via Nanosponge-Embedded Gel: A Novel Approach to Combat Superficial Fungal Infection. Biomedical Materials & Devices. 2025 Oct 15:1-5.
65. Suri SS, Fenniri H, Singh B. Nanotechnology-based drug delivery systems. Journal of occupational medicine and toxicology. 2007 Dec 1;2(1):16.
66. Mullick P, R. Hegde A, Gopalan D, Pandey A, Nandakumar K, Jain S, Kuppusamy G, Mutalik S. Evolving Era of "Sponges": Nanosponges as a Versatile Nanocarrier for the Effective Skin delivery of drugs. Current Pharmaceutical Design. 2022 Jun 1;28(23):1885-96.
67. Alcantara KP, Pajimna RM, Aliga PJ, Malabanan JW, Tangwongsiri C, Haworth IS, Rojsitthisak P, Rojsitthisak P. Review of chitosan-coated nanoscale liposomes for enhanced drug delivery. ACS Applied Nano Materials. 2025 Oct 23;8(44):21125-47.
68. Gilardi G, Fantuzzi A. Manipulating redox systems: application to nanotechnology. TRENDS in Biotechnology. 2001 Nov 1;19(11):468-76.
69. Vankudre S, Shirkoli N, Hawaldar R, Shetti H. Enhanced delivery of dacarbazine using nanosponge loaded hydrogel for targeted melanoma treatment: formulation, statistical optimization and pre-clinical evaluation. Journal of Pharmaceutical Innovation. 2025 Feb;20(1):27.
70. Fisher AC, Lee SL, Harris DP, Buhse L, Kozlowski S, Yu L, Kopcha M, Woodcock J. Advancing pharmaceutical quality: An overview of science and research in the US FDA's Office of Pharmaceutical Quality. International journal of pharmaceutics. 2016 Dec 30;515(1-2):390-402.

How to cite this article:
Shrivastaw AK, Makhija M. Targeted and Controlled Drug Delivery Using Nanosponges: Emerging Trends in Rabeprazole-Based Antiulcer Therapy. International Journal of Pharmaceutical Science and Medicine 2025; 3(3): 105-115.