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A REVIEW ON MICROBEADS

[1]Ms.Mehawish A. Sheikh, [2]Dr. Sayyad Sajauddin Gulab,[3]Mrs.Rubina Sheikh
[1]M.Pharm IInd Year Student, [2]Vice-Principal,[3]Assistant Professor
[1]Pharmacy - Department of Pharmacology
[1]Central India College of Pharmacy , Lonara, Nagpur,Maharashtra,India

Abstract:-Microbeads are small, spherical or near-spherical particulate systems. They have gained a lot of attention in the pharmaceutical field for their potential to contain active pharmaceutical ingredients and to alter drug release properties. These systems are typically made of natural, semi-synthetic, or synthetic polymers. The composition and internal structure can be manipulated to achieve different drug loading capacities, particle characteristics, and release properties.

Natural polymers like sodium alginate, chitosan, gelatin, pectin are commonly used for making microbeads due to their gel-forming properties and pharmaceutical applicability. Synthetic polymers like poly(lactic-co-glycolic acid), polylactic acid, and polycaprolactone are also used for the preparation of biodegradable particulate systems. For making microbeads with the desired properties, several preparation methods such as ionotropic gelation, extrusion, emulsion-based techniques, solvent evaporation, microfluidic techniques are used.

Recently, the potential of microbeads for sustained drug delivery, targeting in the gastrointestinal tract, antimicrobial delivery, protein and other bioactive substances delivery has been shown. Particle size, morphology, % yield, drug content, encapsulation efficiency, swelling properties, and in-vitro drug release studies are generally used for the pharmaceutical evaluation of microbeads. However, several challenges like formulation variability, initial burst release, storage stability, manufacturing scale-up, etc. still need to be addressed.

The basic concepts, classification, polymeric materials, preparation methods, drug release mechanism, evaluation parameters, pharmaceutical applications, advantages, limitations, and recent advances in microbead-based drug delivery systems are reviewed in this article.

Keywords: Microbeads, polymeric beads, sodium alginate, chitosan, controlled drug delivery, sustained release, ionotropic gelation, encapsulation.

1. INTRODUCTION

Drug delivery system development is an important area of research in the field of pharmaceuticals. Conventional dosage forms like tablets, capsules, oral solutions, etc., are commonly used due to their convenience and ease of administration. However, several limitations like frequent dosing, drug concentration variation, early drug release, degradation of sensitive substances, etc., have led to the development of alternative drug delivery systems.

Microbeads are polymer-based particulate systems, which are designed to carry pharmaceutical substances in small bead-like structures. They can be prepared from natural, semi-synthetic, or synthetic polymers, depending on the required properties of the formulation. The drug incorporated in the microbeads can be distributed in the polymeric matrix or encapsulated in a specific region of the beads. These structural variations can affect the drug loading, stability, and release properties [1–4].

Natural polymers have been a subject of interest for the preparation of microbeads. For instance, sodium alginate can form a gel in the presence of multivalent ions like calcium. Chitosan can form polyelectrolyte complexes by interacting with negatively charged polymers. These properties have been exploited for the preparation of polymeric beads with altered swelling and drug release properties [1,5]

Recently, several studies have shown the potential of microbeads for various pharmaceutical applications. For example, Sun et al. prepared pH-sensitive alginate/chitosan-based microbeads for gastrointestinal drug delivery [1]. Boi et al. prepared alginate microbeads with internal microvoids to alter the drug loading and release [4]. Li et al. prepared calcium alginate microbeads with chitosan nanoparticles for controlled release of insulin [8]. Recently, Biji et al. prepared alginate/carboxymethyl chitosan microbeads for the sustained release of celecoxib [17].

These studies show that microbeads offer a versatile platform for the development of pharmaceutical formulations with different drug release characteristics. However, the performance of microbeads depends on the choice of polymers, preparation conditions, drug properties, and route of administration.

2. DEFINITION OF MICROBEADS

Microbeads are small, discrete bead-shaped particles prepared from polymeric or other appropriate materials. They are used in pharmaceutical formulations as carriers to contain active pharmaceutical ingredients and alter their release properties.

The drug can be either distributed in the polymeric matrix or present in internal pores or encapsulated in one or more polymeric layers. The size, shape, surface characteristics, mechanical strength, and drug release properties depend on the materials and preparation conditions used during the preparation [2,4].

Microbeads can be designed for various pharmaceutical applications, such as oral, topical, vaginal, and other delivery routes. The composition of microbeads depends on the physicochemical properties of the drug and the intended purpose.

3. CHARACTERISTICS OF MICROBEADS

The following are the important characteristics of microbeads.

3.1 Particle size

Particle size is an important characteristic that can affect the surface area, drug loading, dispersion properties, and drug release. The size of microbeads can vary depending on the preparation method, polymer concentration, viscosity, and processing conditions.

3.2 Shape and morphology

Microbeads are generally designed to be spherical or near-spherical. The surface of microbeads can be smooth, rough, or porous. The surface morphology can affect the drug incorporation, water penetration, and release properties.

3.3 Polymeric composition

Microbeads can be prepared from natural, semi-synthetic, or synthetic polymers. The choice of polymer affects several important properties, such as swelling, degradation, mechanical strength, and drug release properties.

3.4 Drug incorporation

The active pharmaceutical ingredient can be incorporated in the polymeric matrix or encapsulated in internal pores or enclosed by a polymeric layer. The method of drug incorporation can affect the final drug content and encapsulation efficiency.

3.5 Swelling properties

Some polymers can swell when exposed to aqueous media. This can increase the size of the beads and alter the diffusion of drug molecules through the polymeric structure.

3.6 Drug release properties

The drug release from microbeads can occur by diffusion, swelling, polymer erosion, or degradation. The drug release pattern depends on the composition and structure of the formulation [4,8,9].

4. CLASSIFICATION OF MICROBEADS

Microbeads can be classified based on the polymer used, internal structure, and intended pharmaceutical function.

4.1 Based on polymer composition

A. Natural polymer-based microbeads

Natural polymer-based microbeads are prepared from natural source materials. These polymers are commonly investigated due to their gel-forming properties and pharmaceutical applicability.

Examples of natural polymers:

- Sodium alginate
- Chitosan
- Gelatin

- Pectin
- Starch
- Agar
- Xanthan gum
- Gum tragacanth

Alginate and chitosan are particularly useful for bead preparation because they can form gel structures and interact with appropriate cross-linking agents [1,5,8].

B. Semi-synthetic polymer-based microbeads

Semi-synthetic polymers are prepared by chemical modification of naturally occurring polymers. They can offer increased formulation flexibility and modified physical properties.

Examples of semi-synthetic polymers:

- Hydroxypropyl methylcellulose (HPMC)
- Ethyl cellulose
- Sodium carboxymethyl cellulose
- Hydroxypropyl cellulose

C. Synthetic polymer-based microbeads

Synthetic polymer-based microbeads are prepared from chemically synthesized polymers. They can be tailored to meet the required formulation properties.

Examples of synthetic polymers:

- Poly(lactic-co-glycolic acid) (PLGA)
- Polylactic acid (PLA)
- Polycaprolactone (PCL)
- Polyvinyl alcohol (PVA)

4.2 Based on internal structure

A. Matrix-type microbeads

Matrix-type microbeads have a drug distributed throughout the polymeric structure. Drug release generally occurs by diffusion and may involve swelling or polymer erosion.

B. Reservoir-type microbeads

Reservoir-type microbeads contain the drug in the internal region, which is surrounded by a polymeric barrier. This polymeric barrier can affect the rate at which the drug diffuses into the external medium.

C. Porous microbeads

Porous microbeads have pores or internal voids in their structure. These pores can act as additional sites for drug incorporation and affect the movement of drug molecules.

D. Coated microbeads

Coated microbeads have an additional polymeric layer over the primary structure of the bead. This coating can be used to alter the drug release, improve stability, or offer pH-dependent properties.

E. Gel-based microbeads

Gel-based microbeads are prepared by gelation or cross-linking of polymers. For example, calcium alginate and alginate–chitosan beads are gel-based microbeads [1,4,5].

5. POLYMERS USED IN MICROBEAD FORMULATION

Polymers are the main structural components in many pharmaceutical microbeads. Polymers are selected based on properties such as solubility, viscosity, gel-forming ability, biodegradability, compatibility, and mechanical strength.

5.1 Sodium alginate

Sodium alginate is a natural polysaccharide primarily obtained from brown seaweed. It is commonly investigated for microbead preparation due to its ability to form a gel in the presence of multivalent cations, particularly calcium ions.

For the preparation of calcium alginate beads, a sodium alginate solution is typically added dropwise into a calcium chloride solution. The interaction of alginate chains with calcium ions forms a cross-linked gel structure. This gel structure can encapsulate pharmaceutical substances and affect their release [4,8].

5.2 Chitosan

Chitosan is a natural polymer prepared by deacetylation of chitin. It has amino groups that can interact with negatively charged polymers, such as alginate.

Chitosan can be used alone or in combination with alginate to alter the properties of microbeads. Chitosan-coated or chitosan-containing alginate beads have been investigated for controlled drug release and gastrointestinal delivery [1,5,10].

5.3 Gelatin

Gelatin is a protein-based polymer obtained from collagen. It has gel-forming and film-forming properties and has been investigated for the preparation of polymeric delivery systems.

The applicability of gelatin depends on the formulation conditions, cross-linking method, and intended application.

5.4 Pectin

Pectin is a natural polysaccharide commonly obtained from plant sources. Its gel-forming properties make it a potential candidate for the preparation of polymeric beads, particularly for gastrointestinal drug delivery.

Recently, sodium alginate–pectin hydrogel beads have been investigated for the intestinal delivery of exenatide [20].

5.5 Hydroxypropyl methylcellulose

HPMC is a semi-synthetic cellulose derivative used in pharmaceutical formulations. It has hydrophilic and swelling properties and can affect drug release.

5.6 Poly(lactic-co-glycolic acid)

PLGA is a biodegradable synthetic polymer investigated for pharmaceutical drug delivery systems. Its degradation properties can be altered by changing the composition and molecular properties. It can be considered for the development of polymeric particulate systems with controlled degradation properties.

5.7 Polycaprolactone

Polycaprolactone is a biodegradable polyester used in various drug delivery applications. It has a relatively slow degradation rate, which makes it a candidate for selected long-duration delivery systems.

6. METHODS OF PREPARATION OF MICROBEADS

The following methods can be used to prepare pharmaceutical microbeads: 6.1 Ionotropic gelation method, 6.2 Extrusion method, 6.3 Emulsion-based method, 6.4 Solvent evaporation method, 6.5 Spray drying method and 6.6 Microfluidic method.

6.1 Ionotropic gelation method

A common method for the preparation of polymeric microbeads, in particular of sodium alginate, is the ionotropic gelation method.

The drug is dissolved in the polymer solution to form a homogeneous mixture which is then added dropwise to a solution of cross-linking ions (e.g. Ca2+). Interaction of polymer and cross-linking ions results in formation of a gel.

Beads are collected, washed to remove excess cross-linking solution, and dried.

General procedure:

1. Prepare the polymer solution.
2. Incorporate the drug into the polymer solution.
3. Prepare the cross-linking solution.
4. Add the polymer mixture dropwise into the cross-linking solution.
5. Allow sufficient time for gel formation.

6. Collect and wash the formed beads.
7. Dry the beads under suitable conditions.

For example, pH-sensitive microbeads prepared by alginate/chitosan interactions were investigated by Sun et al. [1], whereas Biji et al. developed alginate/carboxymethyl chitosan microbeads containing celecoxib by means of ionic gelation [17].

6.2 Extrusion method

The extrusion method can be used to produce microbeads by passing a drug containing polymer solution through a suitable needle/nozzle into a receiving medium. The resulting droplets form beads by gelation or solidification.

The particle size of the microbeads formed can be affected by the diameter of the needle, the polymer viscosity, flow rate of the polymer solution and the distance between the nozzle and the receiving medium.

6.3 Emulsion-based method

In the emulsion-based method, a polymer-containing phase is dispersed in another immiscible phase to form droplets. These are subsequently stabilized to form particles by means of gelation, precipitation, etc.

The preparation of microbeads can be carried out according to the polymer and drug used.

6.4 Solvent evaporation method

The solvent evaporation method is particularly suitable for the preparation of polymers that can be dissolved in volatile organic solvents.

The drug is first dissolved in the polymer solution and then the whole is dispersed in the external phase. The solvent is then evaporated and the polymer solidifies to form particles.

A range of solvents can be used to dissolve the polymer and the processing conditions can be varied to obtain particles of the desired characteristics with minimum residual solvent.

6.5 Spray drying method

This method involves the atomization of a liquid feed of drug and polymer into droplets by means of a spray nozzle, and the subsequent drying of the droplets by the means of a drying medium to form particles.

This method can be influenced by the feed concentration, temperature of the inlet air, flow rate of air and the type of the spray used.

6.6 Microfluidic method

The microfluidic technology allows to generate droplets and particles of very uniform size and shape by controlling the flow in small channels.

Yang et al. prepared chitosan-coated magnetic alginate microparticles for controlled and sustained drug release using a microfluidic method [11].

7. MECHANISM OF DRUG RELEASE FROM MICROBEADS

The mechanism of drug release from microbeads is influenced by the polymer, drug solubility, particle size, degree of cross-linking and dissolution medium.

7.1 Diffusion-controlled release

The diffusion of the drug from the internal structure of the microbeads into the dissolution medium is controlled by the concentration gradient of the drug between the interior of the beads and the dissolution medium. The rate of release is controlled by the structure of the polymer and the properties of the drug.

7.2 Swelling-controlled release

Many polymers absorb water and swell. The penetration of water into the microbeads and the subsequent swelling of the polymeric structure can increase the rate of drug diffusion out of the beads.

7.3 Polymer erosion

The erosion of the surface of the microbeads or the disintegration of the interior of the beads can be responsible for the release of the incorporated drug.

7.4 Polymer degradation

Biodegradable polymers can be degraded chemically or enzymatically. This can change the polymer structure and help the release of the incorporated drug.

7.5 Dissolution-controlled release

Drug release can also be controlled by dissolution of the drug itself or of soluble components of the formulation. This type of release is controlled by the solubility of the drug and by the dissolution medium.

The internal structure of alginate microbeads and the degree of cross-linking of alginate–chitosan systems for drug release are described in [4,5,9].

8. EVALUATION PARAMETERS OF MICROBEADS

The prepared microbeads are characterized for their quality, physical properties and pharmaceutical performance in several evaluation studies.

8.1 Percentage yield

The percentage yield is the amount of microbeads obtained after the preparation compared to the theoretical amount of microbeads obtained.

Formula:

Percentage yield (%) = (Practical yield / Theoretical yield) × 100

8.2 Particle size analysis

Particle size and size distribution of the prepared microbeads are determined using suitable particle size analysis techniques.

These techniques can include, for example, optical microscopy, image analysis, etc.

8.3 Shape and surface morphology

The shape and surface morphology of the microbeads can be examined by means of scanning electron microscopy (SEM) in order to obtain information on the physical structure of the beads (e.g. on surface morphology, on the presence of pores, etc.).

Scanning electron microscopy can be used to observe surface morphology, porosity and structural features.

8.4 Drug content

Drug content indicates the quantity of active pharmaceutical ingredient present in a specified amount of microbeads.

The amount of drug can be extracted from the microbeads using a suitable solvent and quantified by a validated analytical method.

8.5 Encapsulation efficiency

Encapsulation efficiency is the percentage of the initially added drug that is encapsulated in the microbeads.

Formula:

Encapsulation efficiency (%) = (Actual amount of drug entrapped / Theoretical amount of drug added) × 100

8.6 Swelling index

The swelling index of the microbeads can be determined by measuring the increase in weight of the beads after immersion in water.

Formula:

Swelling index (%) = [(Weight of swollen beads − Initial weight of dry beads) / Initial weight of dry beads] × 100

8.7 Mucoadhesive properties

For formulations to interact with mucosal surfaces the mucoadhesive properties can be studied using suitable in-vitro tests to determine the ability of the formulation to adhere to a mucosal surface.

8.8 In-vitro drug-release study

In-vitro drug release studies are performed to determine the amount of drug released from the microbeads as a function of time.

Samples of the microbeads are placed in a suitable dissolution apparatus and medium, and samples are taken at predetermined times and analyzed for drug content using a suitable analytical method.

The results are used to compare the release of drug from different formulations.

8.9 Drug-release kinetics

The drug release data can be fitted to the different mathematical models such as:

- Zero-order model
- First-order model
- Higuchi model
- Korsmeyer–Peppas model

The suitability of each model depends on the release data and assumptions of the mathematical model.

8.10 Stability studies

Stability studies are performed to determine the changes in physical appearance, drug content, moisture content, particle size, etc. of the microbeads stored under different conditions.

These parameters have been used in recent investigations of alginate, chitosan and composite polymeric bead systems [4,8,10,17].

9. PHARMACEUTICAL APPLICATIONS OF MICROBEADS

The polymer composition and structure of microbeads can be adjusted to various pharmaceutical applications.

9.1 Sustained drug delivery

The polymer used to prepare the microbeads can be modified to obtain the required release profile of the incorporated drug. The release of drug can be sustained over a period of time.

Boi et al. prepared alginate microbeads with internal microvoids for the sustained release of drug [4].

9.2 Controlled drug delivery

Controlled drug delivery is the release of a drug at a constant rate over a specified period of time. Polymeric microbeads can be prepared to release a drug by diffusion, swelling, erosion or degradation of the polymer.

Park et al. developed chitosan–alginate–gentamicin multicomponent beads and investigated the influence of formulation composition on drug release [14].

9.3 Oral drug delivery

The release of drugs from polymeric microbeads can be modified to release in the gastrointestinal tract. This can be achieved by using polymers with different solubility in different regions of the gastrointestinal tract.

Sun et al. developed pH-sensitive alginate/chitosan/kappa-carrageenan microbeads for colon-targeted release [1]. He and Zou developed sodium alginate–pectin hydrogel beads for intestinal delivery of exenatide [20].

9.4 Protein and peptide delivery

Proteins and peptides are sensitive to environmental conditions such as temperature, humidity and light. Polymeric microbeads have been investigated as suitable carriers for these substances.

Li et al. developed calcium alginate microbeads containing chitosan nanoparticles for controlled insulin release [8].

9.5 Delivery of poorly water-soluble drugs

Many drugs are poorly soluble in water, and can present several difficulties during formulation development. Microbeads can be prepared with suitable polymeric or solubilizing components to modify drug incorporation and release.

Biji et al. developed alginate/carboxymethyl chitosan microbeads containing celecoxib and investigated their sustained-release properties [17].

9.6 Antimicrobial drug delivery

Polymeric beads have also been investigated for the incorporation and release of antimicrobial substances.

Park et al. developed chitosan–alginate–gentamicin beads and studied the drug release and the antimicrobial activity of the beads [14]. Cirri et al. also investigated chitosan and chitosan–alginate microspheres for vaginal administration of metronidazole [10].

9.7 Localized drug delivery

For localized delivery of drugs, the composition of the microbeads can be adjusted to influence the retention, the swelling and the release of the drug at the site of administration.

The potential of polymeric particulate systems for localized delivery has been demonstrated by studies on vaginal microspheres and gastrointestinal-targeted beads [1,10].

10. ADVANTAGES OF MICROBEADS

The important advantages of microbeads include:

1. They can be modified to obtain the required release profile of the incorporated drug.
2. They can be used to incorporate different types of pharmaceutical substances.
3. Their polymeric composition can be adjusted according to formulation requirements.
4. They can be used to protect sensitive substances from certain environmental conditions.
5. They can be used for different routes of administration.
6. They can be used for sustained and site-specific drug delivery.
7. Natural and synthetic polymers can be used in combination to modify the properties of the formulation.
8. Various preparation methods can be used to prepare microbeads of different polymer and drug.

11. LIMITATIONS OF MICROBEADS

The following points discuss some of the limitations of microbeads that need to be taken into account when designing a formulation.

1. Selection of suitable polymers for a particular formulation may require extensive preliminary studies.
2. The amount of drug loaded into the microbeads and the encapsulation efficiency of the drug can vary from batch to batch.
3. The size and shape of the microbeads can be affected by the processing conditions used to prepare them.
4. Many of the methods used to prepare microbeads require the use of organic solvents.
5. In some formulations, there may be an initial burst of drug release from the microbeads.
6. Scale-up of microbeads to commercial scale and reproducible manufacture of the microbeads can be difficult.
7. The long-term stability of microbeads must be established.
8. The polymer and cross-linking agent must be suitable for the route of administration for which the microbeads are intended.

The polymer structure and cross-linking conditions can have a significant effect on the initial drug release from alginate-based and chitosan–alginate bead systems [4,5,14].

12. RECENT RESEARCH DEVELOPMENTS IN MICROBEADS (2019–2026)

Recent studies on the development of polymeric microbeads with optimized characteristics for drug delivery have been reported.

Sun et al. (2019) developed dual-layered pH-sensitive alginate/chitosan/kappa-carrageenan microbeads for colon-targeted drug release. The additional polymer layer in the beads played a critical role in the stability of the beads and the release of the drug under simulated gastrointestinal conditions [1].

Chen et al. (2019) explored the structural and functional properties of magnetic and self-healing chitosan–alginate hydrogel systems containing gelatin microspheres for drug delivery. Their research provided insights into the development of such polymer-based systems for drug delivery [2].

Alginate microbeads with internal microvoids were prepared for the sustained release of drugs by Boi et al. (2020) [4]. The internal architecture of the beads influenced drug loading and sustained-release behaviour.

Wu et al. (2020) developed dual-cross-linked chitosan–alginate hydrogel beads and studied the release of doxorubicin hydrochloride under simulated gastrointestinal conditions. The influence of double cross-linking on the properties of the beads and the drug release was studied [5].

Li et al. (2021) prepared calcium alginate microbeads containing chitosan nanoparticles for controlled release of insulin. The research demonstrated the potential of combining different polymeric structures for incorporating protein-based substances [8].

Chitosan and chitosan–alginate microspheres for vaginal administration of metronidazole were developed by Cirri et al. (2021) and the formulation was characterized and evaluated for its microbiological activity [10].

The microfluidic synthesis of chitosan-coated magnetic alginate microparticles for controlled drug release was investigated by Yang et al. (2021) [11]. The use of microfluidic processing for the synthesis of particles of controlled size and morphology was demonstrated.

Aminoglycoside-loaded chitosan/tripolyphosphate/alginate microspheres were prepared and characterized for their antibacterial properties by Tiburcio et al. (2021) [12].

Quercetin-loaded chitosan–alginate microspheres were prepared by Frenț et al. (2022) using natural polymer combinations to incorporate bioactive substances [13].

Multicomponent beads of chitosan–alginate–gentamicin were prepared by Park et al. (2022) and the influence of polymer composition and cross-linking conditions on the drug-release profile was investigated [14].

Ionically cross-linked alginate–chitosan core–shell hydrogel beads were prepared for the oral delivery of insulin by Phan et al. (2022) [15].

Hybrid alginate–chitosan microparticles containing ketorolac tromethamine were developed for ocular delivery by Fathalla et al. (2023). The formulation was characterized in-vitro and ex-vivo [16].

Alginate/carboxymethyl chitosan microbeads containing celecoxib were prepared by Biji et al. (2024) using ionic gelation and the formulation was optimized for mucoadhesive properties and sustained drug release [17].

pH-responsive chitosan–alginate hydrogel beads containing omeprazole were prepared and the formulation was optimized, in-vitro drug release, permeability and stability were assessed by Philip et al. (2025) [18].

Mohanta et al. (2026 issue; first published online in 2025) prepared sodium alginate–metformin microspheres coated with chitosan using ionotropic gelation and polymer coating for sustained drug release [19].

He and Zou (2026) developed sodium alginate–pectin hydrogel beads containing exenatide and the influence of surfactants on the characteristics of the beads and the intestinal drug-release behaviour was investigated [20].

Continuing interest in the development of natural polymer-based beads, composite polymer systems and advanced manufacturing technologies for pharmaceutical delivery is apparent.

13. FUTURE PERSPECTIVES

Future research on microbeads can be aimed at improving the formulation reproducibility, drug-loading capacity and the release of drugs from the microbeads in a controlled manner. Natural polymer combinations and biodegradable synthetic polymers can be utilized to obtain microbeads with desired physical and pharmaceutical properties.

In addition, advanced manufacturing technologies such as microfluidic processing can be used to control the size of microbeads and to obtain beads with uniform size in a batch. More systematic studies on long-term stability, scale-up, polymer degradation and in-vivo release of drugs from microbeads can be conducted to develop microbead-based drug delivery systems for practical pharmaceutical applications.

More systematic investigations of long-term stability, scale-up, polymer degradation and in-vivo performance will be important for translating laboratory formulations into practical pharmaceutical products.

14. CONCLUSION

Polymer-based particulate systems such as microbeads have the potential to be used for pharmaceutical drug delivery. They can be used to incorporate active pharmaceutical ingredients and to modify the drug-release properties.

The natural polymers such as sodium alginate, chitosan, gelatin and pectin have been widely studied as gelling agents and can be used to prepare different types of microbeads. Synthetic polymers can be used to obtain desired degradation and release properties.

A number of methods can be used to prepare microbeads. These include ionotropic gelation, extrusion, emulsion-based methods and microfluidic processing. The physical and pharmaceutical properties of the microbeads can be modified by the polymer used, drug, preparation method and intended route of administration.

While microbeads have the potential for sustained, controlled and localized drug delivery, further research is required to obtain microbeads with improved formulation reproducibility, stability and scale-up of the manufacturing process. Continued research on

polymeric materials and formulation technologies will lead to the development of more effective microbead-based drug delivery systems.

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