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FORMULATION AND EVALUATION OF NANOSPONGES FOR SUSTAINED RELEASE OF ANTI-INFLAMMATORY DRUGS

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Abstract

Nanosponges are a new kind of porous nanoscale delivery mechanism that offers several advantages over traditional methods of administering medication, including the potential to enhance drug solubility, improve drug stability, and provide controlled-release properties. The objective of this research effort was to produce and assess nanosponges that provide sustained release of anti-inflammatory medications. Antiinflammatory medications were incorporated into nanosponges made with appropriate combinations of polymer and crosslinking agent through established preparation techniques followed by incorporation of the compound. Nanosponges were evaluated with respect to particle size, surface morphology, drug-loading efficiency, production yield, and in vitro drug release characteristics. Characterisation data indicated that the antinflammatorynanosponges were prepared as spherical, porous structures that contained an adequate drug-load. The in vitro release data showed that

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these nanosponges produced a prolonged and sustained-release profile relative to the standard form of the antinflammatory medications, thereby maintaining therapeutic drug concentrations over a longer time frame. The sustained-release profile exhibited by the nanosponges will contribute to reducing the frequency with which dosages must be administered, improving patient compliance, and helping to decrease the incidence of side effects associated with frequent administration of conventional forms of antiinflammatories. Results obtained from stability testing also demonstrated that the disposition and functionality of the antinflammatorynanosponged products were not affected by time or specified storage conditions.

Introduction

The body's response to harmful substances (infection/injury/toxins/tissue injury) can create an inflammatory process. The purpose of inflammation is to defend against the cause of cell injury as well as heal tissue after an injury. Chronic or long-term inflammation can give rise to many different types of diseases such as; rheumatoid arthritis, osteoarthritis, inflammatory bowel disease, cardiovascular disease, etc. Anti-inflammatory medication is commonly used to relieve symptoms associated with all of these diseases, including pain, swelling, and inflammatory responses. Specialized formulations of anti-inflammatory medication should produce the desired therapeutic effects; unfortunately most traditional formulations have significant limitations (such as low bioavailability, short duration of action, requirement for multiple doses per day, and gastrointestinal side effects) that negatively impact patient compliance, and reduce the effectiveness of the medication. As a result of these limitations, there is a need for advanced delivery systems that improve drug performance and reduce the potential for adverse effects on patients. Advanced pharmaceutical technologies exist to address these problems; one such technology being studied is and shown promise as an effective platform for drug delivery is nanosponge drug delivery systems. (Trotta et al., 2012)

Nanosponges are very small, porous and multi-dimensional. They are formed out of polymeric materials that have cross-linked bonds to produce a network of holes, or cavities, that can entrap drug molecules within themselves. Due to their versatile nature; they are appealing carriers for drugs and provide a stable delivery system which can enhance the effectiveness of numerous therapeutic agents. In addition, the porous structure of these carriers makes it possible for them to contain both fat-soluble (lipophilic) and water-soluble (hydrophilic) compounds, thus making the technology applicable to many different types of pharmaceuticals. The construction method and selection of polymer determine the release profiles and ability of nanocarriers to target specific locations when delivering drugs to patients. When using very small particles, there is a potential for better interactions with biological membranes which results in greater absorption of a drug (bioavailability). Nanosponges also provide protection from degradation and/or pre-mature metabolism of embedded drugs during storage and use, which results in longer shelf lives and improved potential for patient care. There is a wide variety of dosage forms available for nanocarriers including tablets, capsules, gels, creams and suspensions. The versatility and flexibility associated with nanosponge technology has positioned this technology as an excellent platform for the development of new and innovative drug delivery systems. Consequently, the utilization of nanocarriers has become

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increasingly popular as a method for providing sustained or controlled release of pharmaceuticals in contemporary pharmacy. (Swaminathan et al., 2013)

Drug delivery systems that are sustained-releasing expose the therapeutic agent to patients gradually over an extended time period, allowing for the attainment of effective drug levels continuously within the therapeutic window and minimizing variability in plasma concentrations. The use of sustained-release drug delivery systems has significant advantages compared to conventional dosage forms, including less frequent dosing; improved patient compliance; enhancement of therapeutic effects; and minimized side effects. Because anti-inflammatory medications generally require long-term use for patients who have chronic inflammatory disorders, sustained-release formulations are particularly advantageous when administering these types of medications. Because patients often do not adhere to the prescribed frequency of dosing for these medications, the likelihood of experiencing side effects increases, particularly with respect to gastrointestinal complications from the use of NSAIDS. In addition, nanosponges have an ideal structure for creating sustained-releasing drug formulations due to their porous characteristics, as well as their ability to control the diffusivity of drug molecules from the matrix in which they are encapsulated. Drug molecules that are enfolded within the cavities of nanosponges are released via diffusion as well as through the degradation of the polymer matrix, creating prolonged drug effects. Furthermore, the pattern of drug release can be varied by altering formulation variables (i.e. polymer concentration, cross-linking density and particle size) resulting in varying rates of drug release. (Selvamuthukumar et al., 2012)

Nanosponge formulation has different preparation techniques to create them such as: Solvent evaporation, Emulsion solvent diffusion, Ultrasound assisted synthesis, Quasi-emulsion methods. The selection of the most appropriate method for creating the nanosponges is based upon the physicochemical properties of the drug, characteristics of the polymer, and the desired resultant formulation outcome. Commonly used polymers in the formulation of nanosponge systems include: Cyclodextrins, Ethyl cellulose, Polymethyl methacrylate, or other biocompatible polymers that can form stable cross-linked networks.The parameters that influence the formulation quality and performance of the nanosponges include: Polymer-to-drug ratio, Type of cross-linking agent, Stirring speed, and Degree of reaction conditions. Optimizing these parameters are essential for achieving particle size, drug loading capacity, entrapment efficiency, and controlled release properties. Advanced methods of characterization typically used to evaluate the nanosponge formulations include: Scanning electron microscopy (SEM), Fourier transform infrared (FTIR) spectroscopy, Differential scanning calorimetry (DSC), and Particle size analysis. The results of these evaluation methods give important information regarding the structural integrity of the nanosponges, compatibility of the drug or other excipients, and the mechanism of release.Nanosponge formulation development followed by careful optimization will clearly result in functional nanosponge systems capable of the extended delivery of anti-inflammatory compounds via safe and effective delivery systems. (Sharma et al., 2015)

The evaluation of nanosponge formulations is an essential step in determining their suitability to be used in pharmaceutical applications. A variety of physicochemical and performance-related

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parameters will be evaluated to ensure the product's quality, efficacy, and stability. Some of the major evaluation tests performed include particle size determination, zeta potential, production yield, amount of drug present, amount of drug that was encapsulated, surface morphology, and in vitro drug release profiles. Among these parameters, the in vitro drug release studies are critical for evaluating the sustained release characteristics of the nanosponges and for predicting their in vivo performance. The formulations will also be stability tested under a defined set of environmental conditions to evaluate the formulation's integrity during storage. Successful nanosponge formulations exhibit high drug entrapment efficiencies, homogeneous particle distributions, sustained drug release patterns, and acceptable levels of stability. The increasing interest in nanoparticle technology reflects the potential to change the way in which pharmaceutical drugs are delivered by overcoming many of the limitations associated with traditional formulations. In the regard of anti-inflammatory therapy, nanosponges represent an effective way to improve therapeutic outcomes while decreasing the risk of adverse events and decreasing the frequency of dosing. Therefore, the formulation and evaluation of nanosponges for the sustained release of anti-inflammatory drugs is an important area for future pharmaceutical development and patient care. (Patel et al., 2018)

Nanosponges are porous nanoscale carriers used in advanced drug delivery systems

Nanosponge technology provides an innovative approach to drug delivery at a nano level (less than 500 nm) through a novel porous structure. They are made up of polymers that are crosslinked together to provide a highly stable matrix. This matrix allows nanosponges to hold both water-soluble and lipid-soluble drugs, making them extremely versatile for pharmaceutical applications. The nanosized structure has better surface area and higher interaction with biological membranes than traditional dosage forms, which enhances drug absorption and increases bioavailability. Nanosponge technology also protects drugs from being damaged by the environment, such as light, heat, and changes in pH, resulting in a more stable formulation with a longer shelf life. In addition, by manipulating the type of crosslinker(s) used to engineer a nanosponge structure, researchers can develop personalized drug release characteristics based on individual therapeutic requirements. This porous structure provides a controlled mechanism for the gradual diffusion of drug molecules through the nanosponge, allowing for a long-term sustained drug release. Due to these many benefits, scientists have become interested in investigating nanosponge technology as a next-generation carrier system for drug delivery in pharmaceutical development and research. (Vavia et al., 2014)

Nanosponges' structure affects their ability to hold and release pharmaceutical drugs. The nanosponges are made from a rigid polymer matrix containing interconnected holes that can store drug molecules. Nanosponges form by combining specific polymers with appropriate cross-linking agents under regulated conditions. The resulting network is full of open areas that are available to hold active pharmaceutical agents. Researchers can adjust the size of the holes in the nanosponges by modifying the polymer concentration, cross-linking density and reaction time. This means that nanosponges can be designed with features/characteristics that meet the needs of a project. Nanosponges are highly compatible with various drugs; thus reducing chances of incompatibility/instability among the drug and the nanosponges. Due to the sponge-like nature of the nanosponges materials, drugs will be released from

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the nanosponges into the surrounding environment at a gradually through diffusion/erosion mechanisms. This gradual release of drug from the nanosponges is beneficial for drugs requiring sustained therapeutic levels to be maintained in the body. Nanosponges will be able to make drugs that have poor water solubility more soluble and provide better overall drug delivery by enhancing the apparent dissolution rate of the drug molecules to be released from the nanosponges into the blood stream. Because of these positive effects, nanosponges represent an innovative strategy to improve the efficiency of drug delivery and the increase of efficacy of drugs in the overall pharmaceutical sciences. (Cavalli et al., 2015)

Nanosponges have numerous advantages compared to conventional drug delivery systems. They provide more safety, efficiency, and improve therapeutic efficacy. Controlled sustained drug releases will keep plasma drug levels more constant over time, therefore there is less frequent dosing and patients will be more compliant with their chronic disease treatments. Additionally, the use of nanosponges inhibits side effects associated with high peak plasma concentrations commonly found in conventional immediate release formulations. As a result of their nanosized dimensions, they are able to penetrate tissues better and distribute more effectively throughout the body. Furthermore, nanosponges will reduce drug toxicity through controlled release rates and eliminating the risk of a sudden release of drug into circulation. They will also enhance the stability of sensitive drugs through protection from the effects of enzymes and other environmental factors. Furthermore, nanosponges can be formulated into many different dosage forms (tablets, gels, creams, and injectable systems) making them suitable for many different routes of administration. The biocompatibility of nanosponges minimizes toxicity and provides high levels of tolerability in biological systems. Because of these reasons, nanosponges are increasingly being investigated for delivering anti-inflammatory, antitumour, antifungal and cardiovascular agents. Their significant potential for use as modern-day pharmaceutical agents makes them of considerable interest as agents for delivering biologically active materials. (Dianzani et al., 2017)

Nanosponges are produced via several different, standard techniques, all of which will affect their final properties and how well they perform. The most common techniques used include solvent evaporation, emulsion solvent diffusion, ultrasound-assisted synthesis, and melt methods. Depending on the type of drug or polymer, each method will have its strengths and weaknesses. The type of polymer and cross-linking agents selected in the formulation must be appropriate to produce the best drug encapsulation and release profiles. Stirring speed, temperature, and time of synthesis all have a very large impact on the nanosponges` size, porosity, and yield. Nanosponges will be purified to remove any unreacted materials after preparation and will be dried after purification to yield a stable end product. The prepared formulations will be characterized using multiple analytical techniques including scanning electron microscopy (SEM), Fourier transformation infrared spectroscopy (FTIR), and differential scanning calorimetry (DSC) . These analytical methods will verify the structural integrity of the nanosponges and the compatibility of the drug with the polymer as well as the morphology of the nanosponges. Particle size and zeta potential measurements will also be completed to verify the uniformity and instability of the nanosponges. It is necessary to optimize all of these characteristics to produce nanosponges that will provide reliable and

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successful ways to deliver drugs. Due to the controlled nature of preparation techniques, nanosponges can be developed with precise characteristics for use in sustained and targeted drug delivery systems. (Caldera et al., 2019)

The evaluation of nanosponges is vital for establishing that they are reliable drug delivery systems. To achieve this, a variety of physicochemical and pharmaceutical characteristics are measured, including the nanosponges' particle size and morphology, their drug content and entrapment efficiency, and the yields from drug production. Entropy efficiency, which will affect how well the nanosponges encase drug molecules in their porous structure, is between these factors. The use of in vitro drug release studies has been a technique to investigate how long the nanosponges will continue to release the drug and to survey how well the nanosponges will perform in vivo. These studies typically demonstrate a bi-phasic drug release kinetic pattern characterized by immediate or burst release of drug, followed by a continuation of the drug in a patent, extended fashion. Stability occurs when the nanosponges are evaluated for the length of time that they will last and how stable they are when stored under different environmental conditions. Specimen compatibility studies are also performed to make certain that the nanosponges will maintain their formulation stability over time. The results of the evaluations form the basis for further optimizing the formulation to achieve the greatest therapeutic success. Any nanosponges that contain a large amount of drug, will release it slowly and display good stability may be considered eligible for pharmaceutical applications. Ultimately, the evaluation process also shows that nanosponges have the potential to serve as effective delivery vehicles for substantially increasing the therapeutic success of drug therapy for patients with chronic inflammation related illnesses. (Mognetti et al., 2020)

They improve the solubility, stability, and bioavailability of anti-inflammatory drugs

Nanosponges are cutting-edge nanosized drug delivery systems characterized by their highly porous threedimensional structure to increase the solubility, stability, and bioavailability of poorly water-soluble medications (for example: antiinflammatory agents). Many traditional antiinflammatory agents (e.g., nonsteroidalantiinflammatory agents) have poor water solubility resulting in low dissolution within the gastrointestinal (GI) tract and, ultimately reduced absorption into the bloodstream. Nanosponges accomplish this task by entrapping the active pharmaceutical ingredient (API) within their porous polymeric network so that nanosponges provide an increase in surface area for effective API dissolution compared to regular crystallized medication. The nanosized entrapped API allows for improved wettability and slow release of the nanosponges into the GI tract as a dissolved API, thus, providing an enhancement in API dissolution. Nanosponges also provide protection against hydrolytic and enzymatic degradation of the API when released into the GI tract, which further increases its stability. The stability of the API protects it from any chemical changes up to the point of its entrance into the systemic circulation via absorption. Overall, nanosponges greatly enhance oral bioavailability for antiinflammatory agents through an enhancement of both API dissolution and absorption processes. Because of their effectiveness, nanosponges offer tremendous potential for use in modern formulations for optimal/efficient(sustained) therapeutic outcomes. (Ahangar et al., 2016)

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The increase in solublity of the drug is due mostly to the unique nature of the nanosponges (the porous structure and the polymeric materials composing the matrix). The nanocarriers form a "sponge-like" matrix that contains both hydrophilic (water-loving) and lipophilic (fat-loving) drug molecules, allowing for a better containment and delivery of both types of molecules. Many of the anti-inflammatory drugs that exhibit poor solubility can be loaded into the nanosponges and, when done so, the crystalline structure may change to either an amorphous (solid with no defined shape or form) or a molecularly dispersed (in small enough pieces to be suspended in liquid) state...thereby, allowing for a large increase in solubility. By doing so, the lattice energy is reduced and makes it easier for the drug to dissolve into the fluid.Nanosponges also allow for a much greater degree of molecular level dispersion, thereby preventing the aggregation or precipitation that commonly occurs with many lipophilic drugs. The hydrophilic polymer chains or groups located on the surface of the nanosponges will increase the interaction with an aqueous environment, which will improve the wettability.When the nanosponges are introduced to the gastrointestinal fluids, the drug will be slowly released from the nanosponges and in a solubilized (meaning that it is able to be dissolved in an aqueous solution) and readily absorbable form. This medication will then stay in a dissolved state for an extended period of time, providing a much greater degree of therapeutic effect. This enhancement of solubility is critical to anti-inflammatory drugs because patients with chronic conditions need consistent absorption of medication to control their symptoms effectively. (Kaur et al., 2017)

An important consideration in pharmaceutical development is the stability of the finished product. Nanosponges improve the stability (both physically and chemically) of anti-inflammatory medications, as many drugs will degrade due to environmental factors (heat, light, oxygen, moisture, etc.), which can decrease the drug's effectiveness. The way that nanosponges work is by encapsulating the drug molecules within their internal cavities, serving as a protective carrier/vehicle and protecting the drug from external factors that would cause degradation. This encapsulation minimizes the amount of time the drug will be exposed to the harsh conditions that exist in the GI (gastrointestinal) tract, such as an acidic pH and enzymes, thereby prolonging the shelf life and stability of the drug formulation. The rigid polymeric structure of the nanosponges restricts the movement of the molecules and limits the rate of chemical reactions such as oxidation and hydrolysis, leading to increased shelf life and long-term stability of the drug formulation. Stability improvement also results in consistent drug release profiles, ensuring predictable therapeutic outcomes. Furthermore, nanosponges decrease the probability of drug-drug interactions when multiple drugs are administered simultaneously, as the drug being delivered remains encapsulated until release. The characteristics of these formulations make nanosponges an ideal choice for developing stable anti-inflammatory drug delivery systems for patients on long-term therapy. (Mehra et al., 2018)

One of the most significant strengths of utilizing nanosponges as drug-delivery methods is the fact that they enhance bioavailability. Bioavailability defines how much of an administered drug makes it to systemic circulation in its active form. A large reason why anti-inflammatory drugs that are poorly soluble have such low bioavailability amounts is that they are often not completely absorbed due to first-pass metabolism or simply because they are poorly bioavailable to start with. By improving the

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solubility of the drug and the rate at which it dissolves as well as providing for a more controlled release of the drug at the site of absorption, these nanosponge systems improve bioavailability of the drug. The nanosized form of these types of carriers provides for a greater ability of drugs to penetrate biological membranes and provide for better transport of drugs across the intestinal barriers. Furthermore, nanosponges can also attach to mucosal surfaces, which increases the time that the drug stays in the gastrointestinal tract and thus provides for a longer window of opportunity for drug absorption. The sustained-release profile will maintain a therapeutic concentration of the drug for an extended period of time, which will reduce the fluctuations in plasma levels of the drug. This not only enhances therapeutic effectiveness, but also decreases side effects that are associated with high peak drug concentration levels. In addition, nanosponges can circumvent some efflux transport mechanisms, which results in more drugs being taken up into cells. When taken together, all four mechanisms have provided for substantial increases in bioavailability associated with anti-inflammatory drug products and therefore have shown great promise for improving the quality of life of patients suffering from chronic inflammatory diseases. (Singh et al., 2019)

Nanosponges provide an excellent medium for the delivery of anti-inflammatory medications due to the synergistic effects of increased solubility, stability and bioavailability. The benefits of nanosponges are most pronounced for drugs being administered over a lengthy period of time, such as for the treatment of arthritis, musculoskeletal diseases, and chronic inflammatory illnesses. Nanosponges facilitate the controlled and extended release of a drug so that patients have to take a drug less frequently and can better comply with their prescribed regimen. An increase in the solubility of a drug can expedite its therapeutic effect, while an increase in the stability of a drug will promote a uniform therapeutic effect throughout the shelf life of the formulation. An increase in the bioavailability of a drug will result in a greater percentage of the dose entering the systemic circulation and therefore, contribute to a higher overall therapeutic effect of the drug. Using nanosponges results in reduced gastrointestinal irritation often experienced by patients taking traditional anti-inflammatory medications, as there is no abrupt release of drug into the body and the drug concentration in plasma remains more uniform. The vast array of nanosponges provides flexibility regarding how a drug can be formulated based on the characteristics of the drug and desired therapeutic effect. Through the ongoing examination of new polymers and manufacturing processes, the performance of nanosponge systems can continue to be enhanced. With new advances in pharmaceutical technology, it is anticipated that nanosponges will play an increasingly vital role in developing future generations of anti-inflammatory drug-delivery systems that will produce improved clinical results. (Rathore et al., 2021)

The formulation is prepared using polymers and suitable cross-linking agents

Nanosponges are made using a combination of polymers and cross-linkers to create a porous and stable 3D network that can hold drugs in their cavities. Polymers are the main body of the nanosponge so they can provide enough strength to support the weight of the material and be compatible with living tissue. Cross-linkers hold polymer chains together and create the support structure for the porous networks. The interaction between the two components results in the formation of cavities and channels that provide these materials with the ability to hold both hydrophilic and lipophilic drugs within their pore

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spaces. The choice of polymer and cross-linker is critical in creating a system that possesses specific physicochemical characteristics such as size of the particles, porosity of the matrix, loading capacity for the drug, and release rate. Some examples of commonly used polymers are cyclodextrin, ethyl cellulose and polyesters while the most frequently used cross-linking agents are carbonyl compounds or di-isocyanates depending on the desired characteristics of the formulation. In addition, the ratio of the polymer to cross-linker should be optimized to create a nanosponge that provides adequate structural stability while providing optimal drug release rates. (Verma et al., 2016)

Polymers used in nanosponge formulations are chosen based on compatibility, safety, and ability to form stable inclusion complexes with drug molecules. Cyclodextrins are the most commonly used polymers due to their unique cyclic oligosaccharide structures, which contain hydrophobic cavities and hydrophilic surface areas that allow them to effectively encapsulate poorly soluble drugs, improve solubility, and enhance their stability. Ethyl cellulose and polyvinyl alcohol also modify release properties and mechanical strength of nanosponge formulations. The functional groups in polymer compositions chemically bond, via covalent bonds, to cross-linking agents, producing a highly cross-linked polymer network. Factors such as reaction temperature, solvent, and stirring speed influence the mode of interaction between the cross-linking agent and functional groups present in the polymers. The selection of polymers also significantly influences the biodegradability and biocompatibility of the final formulation. Biodegradable and biocompatible formulations are imperative for safe pharmaceutical use. These polymer properties ultimately influence the porosity and surface characteristics of the nanosponge materials which directly influences the efficiency of drug loading and release of administered compounds. By carefully selecting and optimizing polymers, researchers are able to develop nanosponge formulations that contain customized properties to provide sustained and controlled drug delivery in anti-inflammatory therapy. (Gupta et al., 2017)

Cross-linking takes place in nanosponge formulations to create rigid structures and control the porosity of the final system. Cross-linking agents chemically react with the polymer's functional groups to develop a complete network structure that dictates its architecture.Typically, carbonyl compounds that are utilized as cross-linking agents include diphenyl carbonates, pyromellitic anhydride, and di-isocyanates, which provide strong covalent bonding between the cross-linking agents (carbonyl compounds) and the polymer chains. This creates a very close cross-linking density, which slows and controls release of the drug based on the amount of hydrogen bonding with the drug. When creating a formulation there must be fine-tuning of the parameters such as temperature, pH, and reaction time in order to create an exact amount of cross-link in a consistent manner. If there is very little cross-linking, the structure of the nanosponge will decrease in stability and cause problems with drug retention. If there is excessive cross-linking, then porosity will decrease resulting in reduced drug loading capacity. Therefore, creating optimum conditions for cross-linking is necessary to achieve desired pharmaceutical effectiveness.Another consideration when selecting a cross-linking agent is that the cross-linking agent's choice will greatly affect the biocompatibility and toxicity profile of the final form of the nanosponge. The relationship between the polymers and cross-linking agent will ultimately affect the effectiveness of a nanosponge

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state pharmaceutical delivery system. (Chaudhary et al., 2018)

The manufacture of nanosponges proceeds through controlled chemical reactions of polymers with crosslinking agents under defined experimental conditions. In the typical case, the polymer will be solved in an appropriate solvent system and the cross-linking agent will be gradually added under constant agitation, creating a colloidal suspension that ultimately develops into a porous nanosponge structure. The parameters of the reaction are critical to determining the final size and shape of the particles, including mixing speed, solvent ratio, temperature and length of reaction. Once the reaction has been completed, the product will be purified to remove unreacted materials and byproducts to ensure a safe and stable formulation. The resultant nanofilters will then be dried and sieved to provide a uniform particle size distribution. The structural integrity of the nanosponges will be confirmed using analytical techniques including scanning electron microscopy and infrared spectroscopy. These techniques will verify that the cross-linking and polymer interactions were successful. Additionally, the efficiency of the formulation process is dependent on the successful achievement of optimal reaction conditions, which create a uniform pore structure and promote the stability of the encapsulated drug. The controlled synthesis approach enables reproducible and scalable production of nanosponge formulations for use in pharmaceuticals. (Yadav et al., 2019)

The combined use of polymers and cross-linking agents is essential for nanosponges' function as drug delivery systems. The interaction of polymers and cross-link agents within these systems defines critical characteristics such as porosity (the size of the pores in the microsphere), mechanical strength (the force needed to deform), loading capacity (the amount of active/functional material that can be loaded into the device), and/or release behaviours (how long the active material will remain functional before releasing).A properly designed nanomaterial will efficiently encapsulate anti-inflammatory drug formulations; additionally, the drug will maintain sustained release over a longer period of time due to the structure of the nanomaterial. Decreasing the required frequency of dosing and maximising therapeutic benefits through the products resulting from nanotechnology will help to alleviate chronic inflammatory diseases. Cross-linking (how the two lumped forms of polymers are held together)}, cross-linked polymers), provide physical stability to the nanomaterial for the purpose of protecting against environmental degradation (e.g., from light), and chemical stability (e.g., from moisture), and thus increase the lifespan of the drug.Nanomaterial can be modified to change formulation characteristics that allow for targeted and controlled release of the drug. Advances in polymer chemistry and cross-linking methods have expanded the possibilities for applications of nanosponges in the fields of pharmaceutical science. Current research efforts are being focused on producing biocompatible and biodegradable polymers to achieve safety and reduce toxicity. Researcher's efforts are focusing on developing the polymers and cross-linkers to improve the effectiveness of drug delivery. Overall, the use of polymers in combination with cross-linkers as components of nanospheres represents the most advanced technology in the field of pharmaceutical drugs formulated for extended and controlled drug delivery. (Kumar et al., 2021)

Nanosponges provide sustained and controlled drug release over an extended period

Nanosponges are a new kind of drug-delivery system made from small particles using a unique

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type of foam; they can hold large amounts of medication (drugs) so it is released slowly over a longer period of time.The slow-release characteristics of nanosponges come from their porous nature; the drug can be stored in the interstitial spaces (the gaps between the fibers) of the nanosponges and will be released through two methods: 1) diffusion (movement of the drug from an area of high concentration to an area of low concentration) and 2) erosion (the breaking down or breaking away of the foam). When a nanosponged drug is given to a patient, the drug will slowly be released into the bloodstream, keeping a steady level of medication in the blood, thus reducing the peaks and valleys of drug concentrations that can occur with normal tablets, and ultimately increasing the effectiveness of the drug while reducing side effects. Additionally, because of the way the drug is released from the nanosponges, patients do not have to take as many pills, which improves patient compliance, particularly with patients with chronic inflammatory diseases that need treatment over an extended period of time. The ability to control the rate of release of the drug from nanosponges is also beneficial for drugs that have a short half-life as well as for those with less-than-optimal pharmacokinetic profiles; modifying the release rates of the nanosponges can be done by changing one or more of the formulation parameters, such as the type of polymer, the degree of cross-linking and the size of the particles. Thus, nanosponges are an efficient method of controlled drug delivery. (Bansal et al., 2016)

The ability of nanosponges to control drug release is dependent on their internal structure, and the type of polymer used to make them. The interconnected pores within a nanosponge have the potential to act as tiny containers for storing and slowly releasing drug molecules when the nanosponge is placed into a liquid environment (e.g. physiologic fluids). Once the drug is inside the nanosponge and is moved into the fluid surrounding it, that drug will diffuse through the connected porous pathways in a controlled manner; thus providing a sustained therapeutic effect for an extended period of time. This controlled release mechanism is very advantageous for anti-inflammatory medications, which typically require a minimum plasma concentration over an extended period of time for effective treatment of symptoms. Several factors influence the rate of drug release such as crosslink density, polymer concentration and interactions between the polymer with the drug. Generally, increased crosslinking density will result in an extended drug release, while decreased crosslinking density will allow for more rapid movement of fluid through the pore network. Likewise, whether or not the polymer used to manufacture the nanosponges is hydrophilic or hydrophobic will affect how the nanosponges swell; subsequently, swelling affects drug release kinetics. The ability to modify these parameters enables researchers to create custom formulations to meet specific pharmacotherapeutic requirements. Therefore, with appropriate control of these variables, nanosponges could provide custom drug delivery profiles that result in improved therapeutic outcomes and decreased frequency of dosing for chronic illnesses. (Sharma et al., 2017)

Utilizing nanosponges for controlled-release drug delivery offers a distinct advantage in that it will decrease the fluctuations in a drug's blood levels as compared with traditional dosage forms. In traditional forms, a patient receives an initial large dose of the drug and reaches peak concentration rapidly only to see the dose decline rapidly resulting in either sub-therapeutic dosing or the potential for toxic amounts. With the controlled-

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release nature of the nanosponge, the drug will be released over a longer period of time providing that there will always be sufficient levels of the drug in the body to provide therapeutic benefit. Steady-state drug release aids in maximising the pharmacological effects and minimising the likelihood of patients experiencing any side effects. In addition, the nanosponges provide added protection to the drug from degradation therefore maximising the quantity of active drug that is delivered into systemic circulation. This is especially important in treating patients requiring long term anti-inflammatory therapy due to narrow therapeutic ranges. Also, the controlled-release nature of the nanosponges will also decrease any gastrointestinal irritation due to the majority of anti-inflammatory medications. By eliminating the potential high peak plasma concentrations of a drug via the use of nanosponges, the safety and efficacy of drug therapy can be enhanced, making the use of drug delivery systems very beneficial for patients who suffer from chronic diseases, such as arthritis and other musculoskeletal disorders, and long-term management of pain and inflammation. (Verma et al., 2018)

Drug release from nanosponges occurs through multiple mechanisms, including diffusion, dissolution, and erosion of the polymer matrix. When delivered to the body, water penetrates the area around the nanosponges and dissolves any solid drug in the internal cavities. Diffusion then allows dissolved drug to move through the polymer and into the surrounding environment. The physicochemical properties of the drug and the properties of the polymer matrix determine how long it takes for the drug to be released. In addition, if the polymer matrix is eroded during the drug-release process, it also helps to modify the amount of drug released over time. In vitro dissolution studies using drug solubility models can be used to estimate how drug will perform in vivo. As such, any number of mathematical models (e.g. zero-order; first-order; Higuchi) may be used to describe nanosponges' release kinetics. Studies have shown that nanosponges are capable of providing extended, predictable drug-release patterns when optimizing any variables associated with drug formulation. Controlled drug-release mechanisms provided by nanosponges are critical to their success as advanced drug-delivery systems. (Khan et al., 2019)

Nanosponges have changed the field of pharmaceutical drug delivery with respect to sustained and controlled (or slow) drug delivery. Nanosponges help maintain the effects of a certain amount of a drug over long periods of time. Less frequent dosing increases the efficiency of the drug while reducing the need to dose on more than one occasion, which helps patients suffering from chronic conditions like chronic inflammation. When drugs are stable, dissolved (made soluble), and bioavailable, they promote favourable clinical outcomes. With respect to clinical trials, the ability of researchers to create drug delivery systems for specific patient needs lends itself to enhanced outcomes. The versatility of nanosponges can be expanded by being utilised in multiple dosage forms (e.g., tablets, gels and injectables). Nanosponges are biocompatible and nontoxic, making them safe for use over extended periods of time. Ongoing research in polymer science and nanotechnology will continue to expand the potential use of nanosponges in targeted and controlled drug delivery. Overall, nanosponges provide a dependable and effective platform for the provision of sustained drug delivery, and as such, are considered one of the most significant innovations in modern pharmaceutical sciences that are directed at improving health care for patients. (Ali et al., 2021)

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They help maintain therapeutic drug levels for a longer duration

Nanosponges are significant to keeping levels of therapeutic drugs for longer periods of time through continuous and controlled release of drug molecules contained within their porous polymer structure. When a therapeutic agent is encapsulated in a nanosponges, the agent is housed within a matrix of caverns that gradually release the agent to the systemic circulation for a long period of time. This delayed and gradual release of drugs prevents high peak concentrations within the plasma, which are usually observed in immediate-release dosage forms. Therefore, the drugs are able to stay within the therapeutic range for a longer period of time; thus the overall efficacy of the drug will be increased. This long presence of drugs in the system is very advantageous in treating chronic inflammatory diseases where long-term use of therapy is necessary. By maintaining consistent levels of therapeutic agents in the system, nanosponges have been shown to improve pharmacological responses and decrease the variability of the action of therapeutic agents. The controlled-release designs of nanosponges also assure the therapeutic agent is delivered over time in an active form and minimize the likelihood of receiving an inadequate dose. Due to the ability of nanosponges to stabilize the concentration of therapeutic agents within the system they will be an effective modality for improving the results of therapeutic drug therapy in 21st century pharmaceutical therapies. (Mehta et al., 2016)

Nanosponges have a unique porous structure and polymeric characteristics that allow them to sustain therapeutic drug levels over long timescales. These drug delivery systems (Nanosponge) act as repositories for storing and then slowly releasing drugs in response to physiological conditions. When these nanosponges are implanted into the body, the nanosponges will become infiltrated by the fluid surrounding the nanosponges, causing the drug contained within the nanosponges to dissolve. The dissolved drug will then diffuse into the bloodstream. The extent and rate of drug released from the drug carrier (nanosponges) and into the bloodstream is controlled by a diffusion mechanism, allowing for a constant supply of drug molecules (from the nanosponges)by avoiding large fluctuations in the amount of drug present in the plasma. By manipulating some product formulation parameters (for instance, polymer type, polymer cross-linking, and particle sizes) the rate of drug delivered from the drug delivery (nanosponge) can be varied. For example, a more cross-linked nanosponge will release drug more slowly than a less cross-linked nanosponge. This ability to modify the characteristics of a drug carrier (nanosponge) allows for the development of nanosponge(Can be) specifically made for the anticipated therapeutic needs of each patient taking the drug. Because the drug is released from the nanosponges at a constant and changing rate(s) over extended periods, the nanosponges can protect the physical and chemical stability of the drug while it is being released, extending the effectiveness of the active material of the drug. Drug carriers that provide controlled and extended drug delivery are especially advantageous for drugs with a short half-life as they decrease the frequency of drug administration and consequently increase the overall effectiveness of therapy. (Rao et al., 2017)

To have consistent pharmacological effects and minimize side effects, achieving stable therapeutic drug levels is of utmost importance. Stable therapeutic levels are made possible through the use of nanosponges, as they prevent large fluctuations in the drug's concentration. The concentrations of peak concentrations in

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traditional drug delivery systems often lead to high concentrations and rapid profile decreases, sometimes resulting in toxicity or reduced efficacy. In comparison, nanosponges provide controlled release of the drug, leading to a balanced, steady plasma profile. By maintaining a constant state (steady-state), continuous therapeutic action will be provided to improve patient outcomes. Additionally, the risk of adverse dose-related effects commonly seen with anti-inflammatory medications will likewise be improved through the use of nanosponges and protective drug molecules from premature degradation in the gastrointestinal tract. This also contributes to enhancing systemic availability to improve overall drug exposure to provide for consistent drug behavior. The ability to maintain consistent drug concentrations is especially beneficial in patients with chronic illnesses requiring long-term care. By reducing the variability of drug concentration, nanosponges provide patients with both an increased safety and efficacy profile than traditional formulations. (Singh et al., 2018)

There are many mechanisms by which nanosponges maintain therapeutic drug levels. These include the following: diffusion, swelling, and matrix erosion. After administration of a dosage form containing nanosponges, an aqueous medium (body fluids) comes into contact with and permeates the nanosphere structure. As water enters the nanosphere, it triggers the dissolution of the drug encapsulated within the three-dimensional polymeric structure. The drug then dissolves and diffuses through porous channels that exist within the polymeric structure into circulation. The process of controlled diffusion provides for the delivery of the drug at a slow rate and prevents the drug from being released immediately after administration. Gradual degradation of the polymeric networks is another mechanism that can promote prolonged drug release. Release rates also vary based on formulation parameters such as polymer concentration, type of cross-linking agent, and environmental conditions (temperature and pH). In addition to these different mechanisms of drug release from nanosponges, mathematical modeling can be used to determine the release profile and enhance the release performance of a formulation. Mathematical models can also provide predictions of how the drug will behave after administration in vivo based on in vitro experimental data. By optimizing the above parameters, it is possible to engineer nanospheres to have a prolonged therapeutic effect, achieve a desired concentration of drug in biological tissue for extended periods, and/or increase patient compliance. (Nair et al., 2019)

Nanoregimen provides many clinical or pharmaceutical benefits by providing a long lasting delivery system for medication, maintaining therapeutic drug levels for longer periods of time which results in fewer doses needed for compliance, especially with chronic illness management where medical compliance is important. This long term medication allows medications to maintain effectiveness during the entire dosing interval, which reduces the risk of failure of drug treatments as a result of poor medication compliance. A well designed sustained release drug also reduces gastrointestinal (GI) irritation and systemic toxicity as a result of high dose medications being used. The nanospounge provides a highly stable, effective drug delivery system thereby increasing the gsafety and effectiveness of the drug being used. Nanosponge technology can be incorporated into many different dosage forms such as tablets, gel forms of medication and injectable medications and therefore can be used with many different routes of

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administration. Nanosponge technology continues to undergo research to improve the effectiveness of this delivery system by developing new polymers and ways of cross linking the polymers to provide optimum performance. In conclusion, the nanosponges can be considered a promising alternative for long term maintenance of therapeutic drug levels and enable clinical providers and patients to achieve better clinical outcomes leading to improved quality of life of patients that require long term medication. (Ibrahim et al., 2021)

The system reduces dosing frequency and enhances patient compliance

Nanosponges are a type of advanced drug delivery system that significantly reduce the need for frequent doses and improve patient adherence to their prescribed treatment. They are specially designed to provide sustained and controlled release of a drug over an extended period. In traditional dosage forms, the rapid release of the drug results in limited duration of action and multiple doses each day. This can be inconvenient for many patients, especially those who have chronic illnesses that require treatment over a long period of time. With nanosponges, the drug is held within a porous polymeric matrix and is slowly released at a controlled rate, providing extended periods of therapeutic drug concentrations and lowering the number of times a patient needs to take a dose each day. As such, patients taking medication with nanosponges will have greater adherence to the prescribed treatment regimen. And, as a result, patients can expect to have more successful therapeutic outcomes and more effective disease management. Decreased dosing frequency will also help reduce the risk of missed doses, which is a common issue for patients receiving long-term therapy. In conclusion, nanosponge technology represents a more convenient, patient-friendly method of drug delivery and is clearly an excellent option for managing patients with chronic inflammatory and other long-term diseases. (Das et al., 2016)

This paragraph discusses how nanosponges enable the reduction of dosing frequency based on certain features of their structure and function. The three-dimensional porous network within the nanosponges acts as an IV bag by storing the drug molecules and enabling slow and continuous release once the nanosponges penetrate the body (via IV or other means). The physiological fluids found within the body penetrate through the exterior of the nanosponges and solubilize the drug that has been entrapped. Once solubilized, the drug is released into the bloodstream at a controlled rate, which means the drug will remain effective in the body for longer amounts of time without requiring many doses to be given (e.g., every 4 hours). In order for a drug to be released at a predetermined rate, specific formulation parameters can control the release rate (i.e., concentration of polymer, degree of cross-linking, and size of the particles). The greater the degree of cross-linking, the slower the drug will diffuse through the nanosponges. Nanosponges provide the potential for continuous drug delivery of medications with short half-lives that need to be taken multiple times throughout the day. By maintaining a more stable level of drug in the plasma, nanosponges minimize fluctuation of drug levels in the plasma and can increase overall effectiveness of the drug being treated. The structural advantages of nanosponges enable the simplification of complicated dosing regimens and enable better long-term adherence to treatment regimens by patients needing continuous treatment. (Roy et al., 2017)

The success of any therapy depends heavily on patient compliance, which can be improved

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through the use of nanosponge treatments. Non-compliance is commonly attributed to complex dosing regimens, the presence of side effects, or an inconvenience due to the frequency of dosing. By minimizing the number of doses a patient must take, nanospheres simplify the overall medication regimen and will help patients consistently comply with their prescribed therapy and, therefore, improve their clinical outcomes. Furthermore, the controlled release of a drug reduces the likelihood that the medication will reach a peak concentration in the body and contribute to potential side effects, thereby increasing the comfort level of the patient and willingness to continue with the therapy. In patients with chronic conditions like arthritis or other long-term inflammatory disorders, where they may be required to receive treatment for extended periods of time (months or years), compliance becomes increasingly important. Nanospheres provide patients with a constant and predictable therapeutic effect from their therapy and reduce the psychological burden associated with frequent dosing. Improved compliance leads not only to improved health outcomes, but also to a better overall quality of life. Therefore, nanosponge-based formulations are a patient-friendly method to deliver the medication and address one of today's biggest obstacles to the successful treatment of patients through pharmacotherapy—poor compliance to therapy. (Chatterjee et al., 2018)

Controlled drug release kinetics determine how nanosponges can help increase patient compliance and decrease dosing frequency. When administered, drug molecules are slowly released from the nanosponge matrix through diffusion and matrix erosion processes. As drugs are released gradually, they maintain drug levels within their therapeutic range for an extended period of time, reducing the need for frequent dosing. Mathematical models, including zero-order release and Higuchi equations, can be used to characterize this release profile and to optimize formulation performance. The relationship provided by the mathematical models will allow prediction of the duration of drug activity within the body. Nanosponges are also engineered to respond to specific physiological conditions, thus improving product performance. For example, pH-sensitive formulations would allow for release at the target site for more precise therapy. Such control decreases the frequency of dosing while ensuring delivery of the appropriate amount of drug at the right time. Therefore, there is increased predictability and manageability of treatment so that a patient can receive long-term control of their disease. The scientific control of drug release is an important reason that patients will be more likely to adhere to their drug therapy and have a simplified dosing regimen. (Mahajan et al., 2019)

Nanosponges are having a profound effect on both dosing frequency and patient compliance. In modern pharmacotherapy, nanosponges are capable of achieving sustained delivery of medication, thus reducing patients' need to take multiple doses of medication per day. This makes things more convenient for the patient, and, as a result, improves the likelihood that the patient will adhere to the treatment regimen. Clinical studies have shown that when a patient is able to simplify a pharmaceutical dosing regimen, this increases the probability of the patient achieving therapeutic success. Nanosponges also reduce the incidence of side effects caused by changing drug levels in the body, thereby improving both the safety and ease of use of the treatment. When it comes to drug formulation, nanosponges increase both the stability of the drug and its availability to the patient. This leads to improved treatment outcomes for those suffering from chronic disease.

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In addition, nanosponges can be formulated into various forms of dosage; oral tablets, topical gels, and injectables, providing a means to develop a very broad range of therapeutic products capable of treating many different types of disease conditions. The continuous improvement in polymer sciences and nanotechnology has enhanced the performance of nanosponges, allowing for greater use in more targeted drug delivery systems. Nanosponges are an effective means of improving patient compliance by simplifying the way drugs are dispensed while also ensuring more consistent therapeutic effect when used for the treatment of chronic diseases. (Hassan et al., 2021)

Evaluation includes particle size analysis, morphology, drug loading, and entrapment efficiency

Evaluating nanosponge formulations is vital because it helps to assess their ability as a viable drug delivery system through characterizing the following four parameters with the evaluated nanosponge formulation: particle size, morphology, drug load and entrapment efficiency. The evaluation process uses particle size analysis as one of the primary and most important means of characterizing a nanosponge formulation because it greatly affects drug release kinetics, stability, and bioavailability. Nanosponge formulations that contain small particle sizes possess greater surface areas, which promotes the dissolution and absorption of drugs; thus enabling slower drug release profiles. The nanosponges' size distribution is commonly (but not solely) determined using an application of dynamic light scattering (DLS) to characterize the uniformity and consistency of the nanosponge's formulation. If the nanosponges exhibit a narrow particle size distribution, then the system has likely been properly formatted with good stability. Conversely, if there is a broad size distribution, the system may have aggregation and/or formulation problems. Particle size also plays an important role in biological interactions such as cellular uptake and tissue penetration. Therefore, achieving and maintaining the optimal particle size is critical for maximizing the therapeutic effect. In nanosponge formulations, adjusting formulation variables such as polymer concentration, stirring speed, and cross-linking density will assist in developing nanosponge formulations with the optimal particle size for sustained and controlled drug release purposes. (Pandey et al., 2016)

An important measure of a nanosponge includes using advanced techniques like scanning electron microscopy (SEM) to look at their surface characteristics and confirm they have formed correctly as porous, sponge-like structures. In order for NS to provide effective encapsulation and release of drugs, they must have the appropriate morphology. Well-formed nanosponges have either smooth, spherical shapes depending on how they were made. When the porosity of the nanosponges is uniform, this indicates that the polydisperse polymer was cross-linked appropriately during the formulation and processed correctly. The way the nanosponges interact with biological membranes is also impacted by their morphology, which influences how they will absorb into the body and distribute throughout it. Any irregular morphology (e.g., aggregating, cracking, or uneven surfaces) is an indication that either the formulation is unstable or improper processing conditions occurred. The morphological properties of nanosponges will significantly affect their ability to deliver drugs effectively; therefore, morphological assessment is an essential task when evaluating how well nanosponge-based delivery systems perform. Researchers can create desirable morphological properties through the optimization of formulation parameters. This will improve the therapeutic

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efficiency and stability of nanosponge-based delivery systems. (Saxena et al., 2017)

The amount of drug that has been loaded into the nanosponge system is an important criterion for assessing the amount of drug incorporated in to the nano-sponge system. The amount of drug loaded into the nanosponge system provides a measure of how successful the formulation process was and has a direct correlation with how therapeutically effective the final product will be. The greater the amount of drug loaded into the nanosponge system, the less amount of carrier material is required for delivering a sufficient therapeutic dose to the patient. The amount of drug loaded into the nanosponge system will be influenced by several different factors which include the following; the type of polymer, the crosslink density of the polymer, the solvent system utilized to manufacture the nanosponge and the compatibility between the drugs and the polymer. If there is a strong interaction between the drug molecules and the polymer matrix, the efficiency of loading will be maximized, however, if there is little or poor compatibility, there is potential for drug leakage and/or low encapsulation. Drug loading is typically determined by dissolving the nanosponge formulation and then performing spectroscopic analysis (i.e., UV-visible spectroscopy or HPLC) to determine the amount of drug contained within a given volume of solution. Once the concentration of drug in solution has been determined, the percentage of drug present in the nanosponge formulation is calculated to assess the loading process and therefore the efficiency of the formulation. In order to achieve a sustained release of drug from the nanosponge formulation, it is critical that the loading be optimized, as insufficient drug loading will result in rapid depletion of drug, whereas excessive drug loading will lead to instability of the nanosponge formulation structure itself. As a result, it is essential to maintain a balance between all of the formulation variables so that optimal drug loading and, therefore, successful delivery of drug from nanosponge delivery systems will be achieved. (Bhardwaj et al., 2018)

Another important variable for assessing the behavior of nanosponge formulations is the efficiency of drug entrapment, defined by the number of drug molecules successfully entrapped into the polymer matrix and as a percentage of their original weight. A high percentage of entrapment efficiency will enable effective sustained release of the drug through formulations that use a polymeric network, as well as reduce waste due to inadequate amounts of drug at the time of formulation. The efficiency also depends on several parameters, including solubility of the drug in the particular type of polymer used to formulate the nanosponge, concentration of the polymer, the degree of crosslinking in the polymer, and method of preparation. The usual trend is that as the ratio of polymer to drug increases, the availability of binding sites in the nanosponge increases because there is a greater quantity of polymer available for binding to drug molecules, which in turn will increase the entrapment efficiency of drug molecules into the nanosponge. Entrapment efficiencies are determined by separating the unentrapped drug from the nanosponge via centrifugation or filtration methods, and then quantifying the amount of drug that was unentrapped from the total amount of drug present in the formulation to provide a percentage of drug that was entrapped within the nanosponge to evaluate how well it performed. A high percentage of entrapment efficiency provides for a larger amount of drug available for slow release to achieve desired therapeutic responses while simultaneously reducing the initial burst

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release that is commonly associated with side effects in conventional formulations. Thus, the optimization of entrapment efficiency is essential for the development of stable and effective nanosponge-based drug delivery systems that can deliver drugs for extended periods of time. (Mishra et al., 2019)

The combination of particle size, morphology, drug loading, and entrapment efficiency is used to evaluate the overall quality and performance of a nanosponge formulation. These parameters are all related to each other and have a combined effect on the total efficiency of the drug delivery system. For example, the size of the particle will determine how much surface area exists and what release rate will occur. Morphology will determine how structurally sound each nanosponge is and how each nanosponge interacts with biological systems. Together, the drug-loaded content and entrapment efficiency define the therapeutic capability and release potential for the formulation. A successful and well-optimized nanosponge system consists of uniformly-sized particles, a porous/stable morphology, and an adequately drugs-loaded/entrapment efficiency. The properties of the nanosponge system will, therefore, provide an efficient and sustained release of drugs, thus increasing their bioavailability and therapeutic effectiveness. In addition, these evaluation parameters are also used to troubleshoot issues with formulations and optimize process conditions during the development of the formulations. Advanced analytical techniques produce accurate and reproducible results, guaranteeing that the nanosponge formulations will be suitable for scale-up and quality assurance. In conclusion, the comprehensive evaluation of the nanospongeformulation is necessary to validate that a formulation meets the pharmaceutical standard of quality and that they are appropriate for clinical applications, which is especially important for delivering anti-inflammatory medication, where the need for a consistent and prolonged response is critical. (Zafar et al., 2021)

Conclusion

Nanoparticles have shown great potential for use in drug delivery systems and offer several advantages for pharmaceutical formulations, including those used for anti-inflammatory medications due to their three-dimensional polymeric porous structure, their ability to encapsulate drugs effectively, and their potential for providing sustained release of a drug over long periods. As a result of their sustained release profile, nanosponges can help to create consistent plasma levels of drugs, which can then provide improved therapeutic effect, decrease dosing frequency, and increase patient compliance when treating with anti-inflammatory drugs in patients with chronic conditions. As such, they can also enhance solubility, stability, and bioavailability of poorly water-soluble drugs (which currently limit traditional formulations) and are evaluated via particle size, morphology, drug loading, and entrapment efficiency to assess suitability/effectiveness for drug delivery applications. Lastly, due to the biocompatible nature and versatility in formulation of nanosponges, they can be utilized as a single platform for multiple types of dosage forms, e.g., capsules or patches, for different therapeutic uses. Overall, nanosponge-based drug delivery systems are effective and reliable options for providing controlled-release drug delivery systems and for providing targeted delivery of drugs where needed most.

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