Review Article

Advances in Novel Drug Delivery Systems

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Abstract

The increasing need for treatments that are safer, more patient-friendly, and more effective has given NDDS significant impetus in recent years. Due to rapid metabolism, enzymatic degradation, or poor permeability across biological barriers, traditional dosage forms frequently fall short of achieving optimal therapeutic levels. In order to address these problems, NDDS uses novel materials and delivery systems that make it easier for medications to overcome physiological obstacles. For instance, hydrophilic and lipophilic medications can be encapsulated in nanocarrier systems like liposomes and polymeric nanoparticles to improve cellular uptake while preventing degradation. Active targeting, in which ligands direct the medication directly to diseased tissues to reduce off-target effects, is made possible by their capacity to be surface-modified. The drawbacks of conventional drug delivery, such as low bioavailability, instability, rapid drug release, and fluctuating plasma concentrations, are addressed by novel drug delivery systems (NDDS), a state-of-the-art technique. This study emphasises the evolution, significance, and applications of NDDS in modern therapies. The article discusses a range of carrier-based systems, including liposomes, nanoparticles, microspheres, and niosomes, as well as transdermal techniques like sonophoresis, osmotic pumps, and microencapsulation. The key features, advantages, disadvantages, and factors influencing NDDS performance are examined. Particular focus is placed on the composition, production processes, and potential for targeted, controlled, and long-term drug delivery of polymeric nanoparticles and liposomes. Thanks to advancements, NDDS plays a revolutionary role in improving therapeutic efficacy, patient compliance, and overall therapy outcome. In a similar vein, sophisticated transdermal delivery methods improve therapeutic consistency by avoiding first-pass metabolism and offering sustained release. The skin barrier is momentarily disrupted by methods like sonophoresis and microneedle arrays, allowing larger or hydrophilic drug molecules to effectively penetrate. Osmotic pumps provide long-lasting and consistent dosing by ensuring controlled release based on osmotic pressure differences. NDDS continues to develop towards precision and personalised medicine as research advances, providing individualised treatments that are in line with the needs of each patient and particular disease profiles. This development emphasises how important NDDS will be in determining how pharmaceutical therapy develops in the future.

Keywords: Sustained release, NDDS, nanoparticles, drug release, bioavailability.

Introduction

The goal of innovative drug delivery systems is to continuously deliver drugs to the bloodstream at predictable and repeatable kinetics over an extended period of time. There are many different grade levels of New Drug Delivery System (NDDS) carriers. The problems with traditional formulations include overdose, instability, initial effects, fluctuations in plasma concentration, and fast release. Basic: Efficacy, protection, patient compliance, and product shelf life. These issues will be handled by NDDS. The drug delivery landscape is undergoing a dramatic transformation with the introduction of Novel Drug Delivery Systems (NDDS), which promise a new era of precision and efficacy in therapeutic treatments. By examining the most recent findings, advancements, and their potential to fundamentally alter how we use and administer medications, this comprehensive analysis seeks to unravel the intricate web of NDDS.[1-5] Poor patient adherence, off-target effects, and inadequate bioavailability have historically plagued conventional medication administration methods. Novel drug delivery systems are new methods used in modern medicine when certain drugs don't work well for serious illnesses. To ensure controlled drug distribution, this approach either combines the medication with a carrier or modifies the drug's molecular structure. These will control the drug's efficacy, toxicity, immunogenicity, pharmacokinetics, and pharmacodynamics. Once only a fantasy, a novel way of delivering medication is now a reality. Developing new drugs with safe and effective treatments has been standard procedure, but it has been very costly, time-consuming, and labour-intensive. Because the drug acts appropriately at target areas, it was later found that the drug's distribution within the biological system has a significant impact on the system's efficacy and safety. Nowadays, people are paying more attention to nanoparticles as they become more aware of their advantages for the environment and how they affect human health and environmental sustainability.[7-10] Numerous methods are used in a wide range of applications to create nanoparticles. Nanoparticles range in size from 10 to 100 nm. When producing nanoparticles, a variety of factors must be taken into account, such as release pattern, size, and surface characteristics that define the specific surface. Understanding the effects of using the right medication on quality and cost is also crucial. For example, polymeric nanoparticles may contain proteins or drugs. These bioactive substances may be retained in the polymer matrix in solid or solution form, or they may be chemically or physically present on the surface.[5] The process of preparing nanoparticles can involve the use of drugs for premade nanoparticles. These bioactive substances may be trapped as solid solutions or particles, or they may be chemically or physically bonded to the particle surface.These bioactive compounds can be chemically or physically bonded to the particle surface, or they can be trapped as solid solutions or particles in the polymer matrix.While the nanoparticles are being manufactured, the medicine or drugs can

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be added. Both biodegradable and non-biodegradable polymers can be used to create drug-carrying nanoparticles. This thorough analysis explores the fascinating realm of NDDS, revealing its mysteries and demonstrating its revolutionary potential. The different nano drug carriers are displayed in the list below.[9,1]

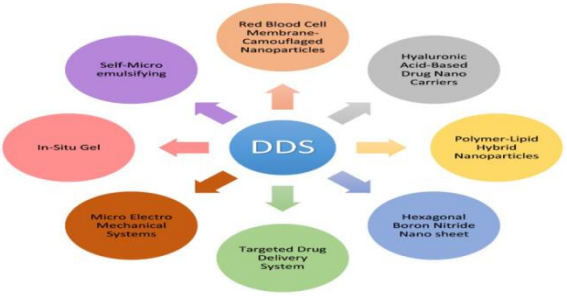

Fig 1:Classification of Drug Delivery System

Definition

Novel Drug Delivery Systems (NDDS) are cutting-edge methods and tools created to improve pharmaceutical safety, therapeutic efficacy, and patient compliance. These technologies enable controlled release, target specific body regions, and increase the bioavailability of medications.[11-14]

Features of Novel Drug Delivery System

1. Increase the bioavailability
2. Easy to administer, safe and reliable.
3. Deliver the medication in a controlled
4. economical manner.[1]
5. Factors affecting NDDS
6. Chronic therapy
7. Physicochemical property of drug molecules are of the main factor of drug efficiency.
8. Site of action
9. The disease level
10. NDDS also differ on Route of drug administration[15]

Advantages of novel drug delivery system

It offers consistent delivery.
The distribution of tissue macrophages was enhanced by NDDS.
Drugs are protection from physical and chemical degradation.
Enhancement of pharmacological activity.
Enhancement of drug stability.[13]

Disadvantages of novel drug delivery system

Requires highly sophisticated technology for the formulation of NDDS drugs.
requires skilled man power for manufacturing, storage and administration.
Dose dumping can occur.
The immune reactions can be occurred against intravenous administered carrier systems.
Difficult to maintain stability of dosage forms.
Drug loading can be slow.[16-19]

Carrier based Drug Delivery System

A Liposomes
B) Nanoparticles
C) Microspheres
D) Niosomes

Transdermal Drug Delivery Systems

Sonophoresis
Osmotic pump
Microencapsulation

Carrier based Drug Delivery System

LIPOSOMES- Liposomes are a type of vesicle made up of one, several, or many phospholipid bilayers. Polar medicinal molecules can be encapsulated due to the polar nature of the liposomal core. Depending on their affinity for the phospholipids, amphiphilic and lipophilic compounds are solubilized within the phospholipid bilayer. Niosomes are produced when nonionic surfactants, rather than phospholipids, participate in the bilayer building process. Channel proteins function as a size-selective filter that only permits the passive passage of tiny solutes such ions, nutrients, and antibiotics within the hydrophobic domain of vesicle membranes without losing their activity. Consequently, drugs enclosed in a nanocage functionalised with channel proteins are effectively protected from the early degradation caused by proteolytic enzymes. Nonetheless, the drug molecule can diffuse through the channel due to the concentration difference between the inside and outside of the nanocage. These "smart" liposomes may be used to treat inflammatory diseases or infections that require precise temporal and spatial control of drug release. Despite its advantages, issues like high production costs and potential instability during storage are also being looked into.[20-22]

Material Used:-

Diethyl ether or ether/methanol mixture

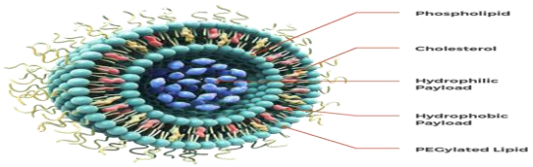

Fig 2: Structure of Liposome

Manufacturing of liposomes

There are several ways to formulate liposomes. The final features of liposomes are significantly influenced by the phospholipid type and the manufacturing procedure. The processes used to create liposomes can be divided into:

The Bangham method of thin-film hydration

Using a round-bottom flask, all lipids and the hydrophobic medication are dissolved in an appropriate organic solvent. A thin film layer was then produced as the organic solvent gradually evaporated at lower pressure. The produced thin film is subsequently hydrated using an aqueous buffer solution at a temperature greater than the transition temperature (Tm) of the used lipid. A hydrophilic material or drugs to be added to the liposomes' aqueous core may be present in the hydration solution. The effectiveness of drug encapsulation is influenced by the rate of hydration. A slower rate of hydration results in an increase in encapsulation efficiency. Particle distributions, lamellarity types, and liposome resizing can be controlled by either extrusion through polycarbonate membranes with particular pore sizes or bath or probe sonicators. Compared to sonication, the extrusion method yields more stable liposomes with higher encapsulation efficacy. In addition to producing SUV liposomes, sonication can hydrolyse or degrade encapsulated medications and/or lipids.[23-25]

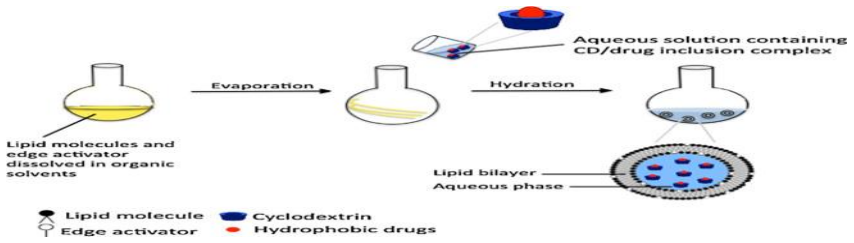

Fig 3:Thin Film Method

Reverse phase evaporation technique

The reverse phase evaporation method is based on inverted micelles or water-in-oil emulsions, in which the organic phase is made up of lipids to form liposomal bilayers and the aqueous phase contains the drugs of interest. To make lipid films, we place this lipid mixture in a flask and allow the solvents to evaporate. The lipid films are then dissolved again using the organic phase, which is primarily made up of isopropyl and/or diethyl ether. A homogeneous dispersion is produced by the sonication that follows the addition of the water phase, which produces a two-phase system. As the organic solvent gradually evaporated, the mixture solidified into a thick gel that contained liposomes in an aqueous suspension. Higher internal aqueous loading is one advantage of the reverse phase evaporation method over the thin-film hydration method. Even though some organic solvent may still be present and could interact with the lipids or the drugs, methods like centrifugation and dialysis can be used to remove it

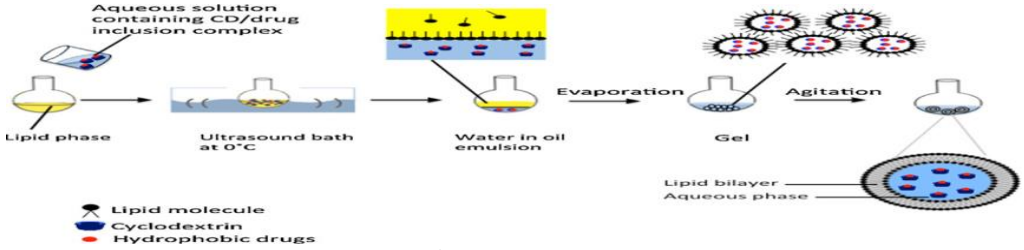

Fig 4: Flow Chart of Reverse Phase Evaporation Method

Type, Description, Benefits, Applications

Type	Description	Benefits Applications
Conventional Liposomes	Drug delivery for variety of disease, and disorders.	Enhanced drug solubility, bioavailability, controlled delivery potential.
Cationic Liposomes	Gene therapy, DNA delivery, non-viral vector delivery.	Efficient gene transfection, enhanced cellular uptake,potencial for targeted delivery.
Steath Liposomes	Cancer therapy, drug delivery to specific tissues.	Reduced clearance by reticuloendothelial system, longer circuation time improved tumor targeting.
Stimui-Responsive Lisosomes	Targeted drug delivery to diseased tissue controlled release based on biological cues	Enhanced therapeutic efficacy reduced side effects, imoproved drug targeting potencial.
Multifuntional Liposome	Targeted therapy for specific disease diagnosis and treatment integration.	Increased drug delivery efficacy, real-time tracking of drug delivery, personalized medicine potencial.

NANOPARTICLES

Nanoparticles, which include nanospheres and nanocapsules with sizes between 10 and 200 nm, can be crystalline or amorphous in their solid state. They can adsorb or encapsulate a drug, protecting it from chemical and enzymatic degradation. Nanocapsules are vesicular systems in which the drug is enclosed in a cavity with a unique polymer membrane, whereas nanospheres are matrix systems in which the drug is physically and uniformly distributed. Drug-carrying nanoparticles can be made from both biodegradable and non-biodegradable polymers. Due to their potential for controlled drug release, targeting particular organs or tissues, acting as DNA carriers in gene therapy, and delivering proteins, peptides, and genes orally, biodegradable polymeric nanoparticles have attracted a lot of attention as potential drug delivery vehicles in recent

years. Due to their potential for controlled drug release, targeting particular organs or tissues, acting as DNA carriers in gene therapy, and delivering proteins, peptides, and genes orally, biodegradable polymeric nanoparticles have recently attracted a lot of attention as potential drug delivery vehicles.[20] These particles have the ability to penetrate the epithelial tissue of tiny blood vessels and penetrate deeply into the tissues. They can enter the systemic circulation without forming platelet aggregates. They have a large surface area due to their smaller particle size, which speeds up drug release. Drug delivery rate and particle integrity can be modulated and controlled using engineered carriers, which can be triggered by changes in the pH of the surrounding environment, chemical stimuli by applying a engineered carriers allow for the modulation and control of drug delivery rate and particle integrity, which can be triggered by changes in the pH of the surrounding environment, chemical stimuli through the application of a fast oscillating magnetic field, or an external heat source. Drug delivery systems make substantial use of nanoparticles. They can offer regulated release, encapsulate medications, and shield them from deterioration. The selective accumulation of nanoparticles in tumor tissues is made possible by the increased permeability and retention (EPR) effect. Because of their special qualities and prospective uses in a variety of industries, nanoparticles are still the subject of substantial research.[26-30]

Composition:

Depending on their intended function, nanoparticles can be made of a variety of materials. Gold, silver, silica, polymers, and lipids are examples of common materials. Every material has unique qualities that can be customised for specific uses.

Types:

Organic Nanoparticles:-
Liposomes
Dendrimers
Polymers
Micelles
Emulsion
Nanogel
Inorganic Nanoparticles:-
Gold NP
Silica NP
Quantum dot NP
Iron NP
Carbon-based:-
Carbon nanotubes
Fullerene
Graphene

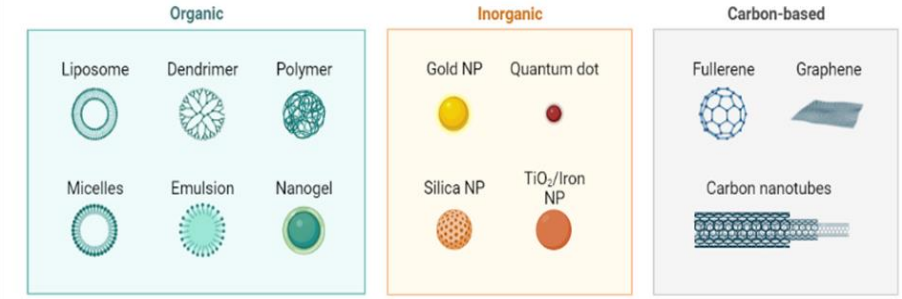

Fig 5: The schematic classification of Nanoparticles

Method of Preparation

The two main categories of nanoparticle manufacturing methods are polymerization of monomers and dispersion of premade polymers. The following are some methods for spreading premade polymers:

Salting out/emulsion diffusion method.
Spontaneous emulsification method.
Nonaqueous phase separation method.
Solvent evaporation method.[29]

Microspheres

One drug delivery method that has been extensively studied in cancer chemotherapy is microspheres. They are essentially solid porous particles (diameters ranging from 1 to 100 µm) that can both target their drug load by physically capturing it in blood vessels (chemoembolization) and sustain the therapeutic agent's effect through controlled-release polymeric materials, such as proteins, polysaccharides, polyesters, and lipids, using a variety of methods (emulsification, thermal stabilization, and phase inversion technology).[29,17]

METHOD OF PREPARATION:

The various methods of preparations are:

Emulsion Solvent Evaporation Technique

Using this technique, the drug is dissolved in a polymer that has previously been dissolved in chloroform. The resulting solution is then added to an aqueous phase that contains 0.2 percent sodium PVP as an emulsifying agent. The medication and polymer were separated into fine droplets after being agitated at 500 rpm. These droplets were then collected by filtration, rinsed with demineralized water, and allowed to dry for a full day at room temperature. Solvent evaporation produced the solidified microspheres.[21]

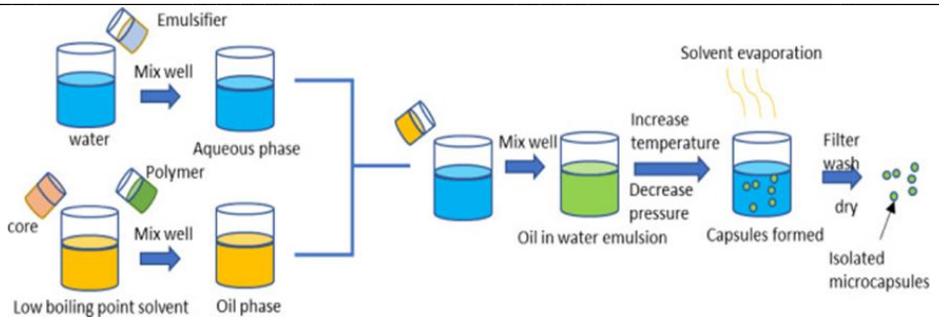

Fig 6:- Microspheres by Solvent Evaporation Technique[29]

Transdermal Drug Delivery Systems:

Sonophoresis

Sonophoresis, also known as phonophoresis, is a non-invasive technique that uses low-frequency ultrasonic waves to improve the passage of drugs or other therapeutic materials through biological barriers, primarily skin. This method greatly accelerates the absorption of topical medications (transdermal administration) into the skin's dermis, epidermis, and appendages by using ultrasonic radiation. It's a promising way to deliver medications to specific target areas, boost bioavailability, and potentially reduce side effects. Hospitals frequently use sonophoresis to administer medication through the skin. In order for the ultrasound transducer to deliver ultrasonic energy to the skin, chemists combine the medications with a coupling agent (gel, cream, or ointment).[30-35]

Mechanism of Action

Although sonophoresis has attracted a lot of attention lately, its mechanisms remain unclear. acknowledged, taking into account the potential for several incidents following ultrasound exposure. These include:

Cavitation (gasbubble production and oscillation).

Convective transport is induced.

Thermal effects (raising the temperature).

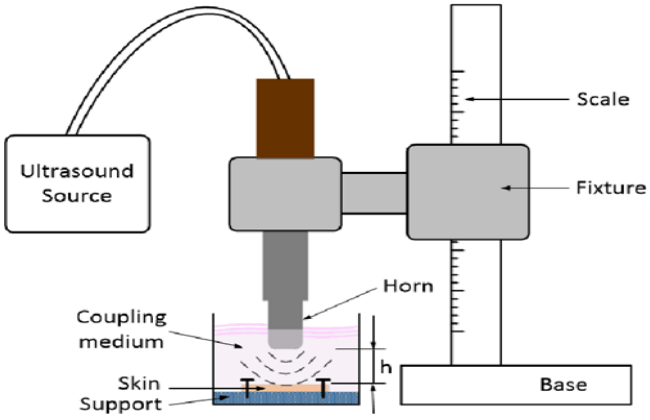

Fig 7: Process Of Sonophoresis

Osmotic pump

The osmotic pump is a drug delivery device that uses osmotic pressure to deliver a controlled and consistent rate of drug release over an extended period of time. These allow the drug to be administered gradually as a suspension or solution because they have one or more drug delivery pores in a semi-permeable membrane covering them. The core of an oral osmotic system is a compressed tablet covered in a semi-permeable membrane through which delivery orifices are drilled using a laser beam or a mechanical drill. Numerous gastrointestinal factors have no effect on these regulated systems, which depend on osmosis and osmotic pressure. But it's crucial to remember that several crucial elements, such as drug solubility, delivery holes, osmotic pressure, and semi-permeable.[11] However, it is important to keep in mind that a number of critical factors, including drug solubility, delivery orifices, osmotic pressure, semi-permeable membrane, and others, influence the design of osmotically controlled drug delivery systems, including membrane thickness, plasticizer type and quantity, and polymer type and nature.[19]

Mechanism:

The drug solution or suspension is forced through a delivery aperture at a regulated rate by this pressure.

This layer protects the enclosed material from outside influences and regulates its release.

The device is made up of a semi-permeable membrane that encloses a compartment that holds the medication and an osmotic agent.

Osmotic pressure is produced when the system is exposed to bodily fluids because water seeps through the membrane and into the apparatus.

The active substance is surrounded by a protective coating, usually comprised of polymers, lipids, or proteins.[10,27]

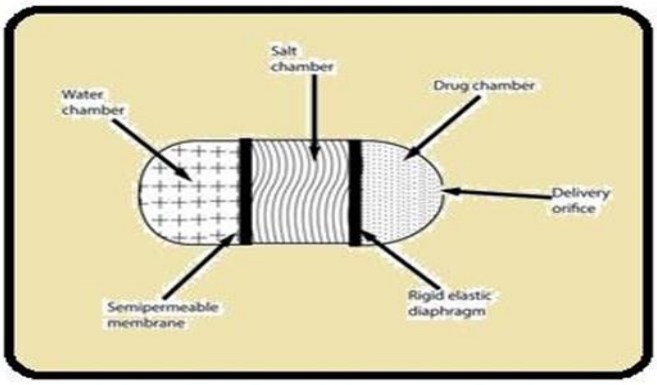

Fig 8:The Rose–Nelson pump

Microencapsulation

Small liquid or solid droplets or particles are covered or encased with a continuous polymeric layer during the microencapsulation process. The gelatin coacervation process was initially used to produce gelatin spheres for the microencapsulation technology, which was created by Bungen burg de Jon and Kan in 1931. The controlled drug delivery system has been used to lessen the negative effects of traditional therapy and increase the therapeutic efficacy of a specific medication. The active component must be delivered to the target tissue at the ideal rate in order to optimise therapeutic efficacy and reduce toxicity and side effects.[28] It is possible to convert liquids into solids, modify surface and colloidal characteristics, safeguard the environment, and alter the release characteristics of various coated materials. Liquids can be transformed into solids, surface and colloidal properties can be changed, the environment can be protected, and the release characteristics of different coated materials can be controlled with the help of microencapsulation. Micromanaging techniques can accomplish some of these features in contrast to microencapsulation, which uses tiny coated particles to create a wide range of dosage forms.[4]

Purpose for Microencapsulation:

Isolation of the core from its environment, such as separating vitamins from oxygen's degrading effects.
Preventing a volatile core from evaporating.
Making a sticky material easier to handle.
Preventing chemical attack on a reactive core.
To handle hazardous items safely.
To obtain a targeted medication release.[10]

Benefits of Microencapsulation:-

Reduces the frequency of doses, which increases patient compliance.
The ability of microspheres to target tumours with anticancer drugs has attracted a lot of attention.
Under controlled circumstances, solid biodegradable microspheres can release medications throughout the particle matrix.
A reliable way to get the drug to the right place and maintain the necessary concentration there without having negative side effects.[29]
The drawbacks of microencapsulation:
It is challenging to produce a consistent, continuous film.
Needs expertise.
The procedure is costly.
Techniques for Microencapsulation
Techniques for solvent evaporation
Pan coating
Congealing and spray drying
Multi-orifice centrifugal method
Phase separation during coacervation
Air suspension[36-40]

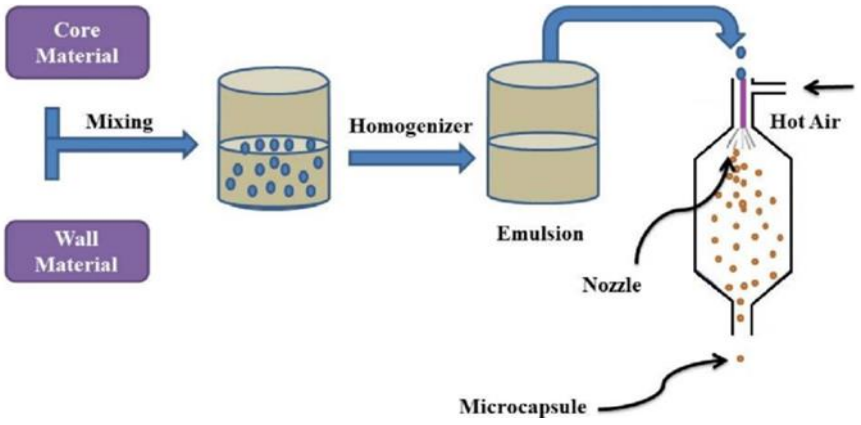

Fig 9: The microencapsulation process

Conclusion

Future developments in interdisciplinary sciences like biotechnology, molecular engineering, materials science, and artificial intelligence will have a significant impact on NDDS. These developments are making it possible to develop intelligent delivery systems that can precisely release medications when and where they are needed by reacting to physiological cues like pH, temperature, enzymes, or external stimuli. These stimulus-responsive nanoparticles and hybrid delivery systems have enormous potential for treating complicated illnesses where traditional treatments frequently fail, such as cancer, neurodegenerative diseases, and chronic inflammatory conditions. By overcoming the drawbacks of conventional drug delivery techniques, novel drug delivery systems mark a substantial breakthrough in the pharmaceutical industry. By increasing medication stability, targeting effectiveness, controlled release, and bioavailability, NDDS improves therapeutic performance. While transdermal techniques increase the number of non-invasive delivery alternatives, carrier-based systems like liposomes and nanoparticles offer creative ways to transfer and safeguard medications. NDDS continues to advance with continued research and technology advancements despite obstacles such formulation complexity, stability problems, high manufacturing costs, and possible immunological reactions. NDDS is anticipated to further transform drug administration by providing safer, more efficient, and patient-friendly therapy options as cutting-edge materials and engineering processes advance. Additionally, NDDS innovations are expected to have a significant positive impact on personalised medicine. Customising drug carriers to each patient's unique genetic, biochemical, and physiological profile can greatly enhance treatment results while reducing side effects. Theranostic systems, which integrate therapy and diagnostics on a single platform, may also result from the integration of NDDS with diagnostic instruments like imaging agents or biosensors. To guarantee that these technologies are more widely accessible, cost-effective production techniques, improved quality-control methods, and regulatory changes will be crucial. NDDS will continue to transform the pharmaceutical industry by providing safer, more focused, and more effective therapeutic solutions for a wide range of medical conditions as these issues are progressively resolved.

References

1. Sharma P., Gajula K., Dingari N.N., Gupta R., Gopal S., Rai B., Iacocca R.G. Subcutaneous drug delivery: a review of the state-of-the-art modelling and experimental techniques. J. Biomech. Eng. 2022 doi: 10.1115/1.4055758.
2. Misbah Ul Haq M., Razzak M., Uddin M.A., Ahmed N., Shahidulla D. Rectal drug delivery system: an overview. Clin. Pharmacol. Biopharm. 2021;10
3. Mahant S., Sharma A.K., Gandhi H., Wadhwa R., Dua K., Kapoor D.N. Emerging trends and potential prospects in vaginal drug delivery. Curr. Drug Deliv. 2022 doi: 10.2174/1567201819666220413131243.
4. Cho M., Joo M., Kim K., Wook Y., Lee S., Mi Y., Ho I. Biochemical and Biophysical Research Communications the immunotherapeutic effects of recombinant Bacillus rin resistant to antimicrobial peptides on Calmette-Gu e bladder cancer cells. Biochem. Biophys. Res. Commun. 2018 doi: 10.1016/j.bbrc.2018.12.097.
5. Palugan L., Cerea M., Cirilli M., Moutaharrik S., Maroni A., Zema L., Melocchi A., Uboldi M., Filippin I., Foppoli A., Gazzaniga A. International Journal of Pharmaceutics : X Intravesical drug delivery approaches for improved therapy of urinary bladder diseases. Int. J. Pharm. X. 2021;3
6. Verma R., Garg S. 2001. Current Status of Drug Delivery Technologies and Future Directions. [Google Scholar]
7. Keraliya R.A., Patel C., Patel P., Keraliya V., Soni T.G., Patel R.C., Patel M.M. Osmotic drug delivery system as a part of modified release dosage form. ISRN Pharm. 2012 doi: 10.5402/2012/528079. 2012.
8. Mattos B.D., Rojas O.J., Magalh W.L.E. Biogenic silica nanoparticles loaded with neem bark extract as green. slow-release biocide. 2017;142:4206–4213.
9. Ding C., Li Z. A review of drug release mechanisms from nanocarrier systems. Mater. Sci. Eng. C. 2017;76:1440–1453.
10. Chen K., Chen X. 2010. Design and Development of Molecular Imaging Probes; pp. 1227–1236.
11. Faheem A.M., Abdelkader D.H. Elsevier LTD.; 2020. Novel Drug Delivery Systems. 1. [DOI] [Google Scholar]
12. Pathak C., Vaidya F.U., Pandey S.M. Elsevier Inc.; 2019. Chapter 3 - Mechanism for Development of Nanobased Drug Delivery System.
13. Danhier F., Feron O., Préat V. To exploit the tumor microenvironment : passive and active tumor targeting of nanocarriers for anti-cancer drug delivery. J. Contr. Release. 2015;148:135–146.
14. Agrahari V. 2018. Novel Drug Delivery Systems, Devices, and Fabrication Methods; pp. 303–306. [DOI] [PubMed] [Google Scholar]
15. Patra J.K., Das G., Fraceto L.F., Vangelie E., Campos R., Rodriguez P., Susana L., Torres A., Armando L., Torres D., Grillo R. Nano based drug delivery systems : recent developments and future prospects. J. Nanobiotechnol. 2018:1–33.
16. Li X., Malardier-jugroot C. 2016. Folic Acid-Conjugated Amphiphilic Alternating Copolymer as a New Active Tumor Targeting Drug Delivery Platform; pp. 4101–4110.
17. Akala E.O. Theory Pract. Contemp. Pharm. CRC Press; Florida: 2004. Oral controlled release solid dosage forms; pp. 333–366.
18. Malm C.J., Emerson J., Hiait G.D. Cellulose acetate phthalate as an enteric coating material. J. Am. Pharm. Assoc. (Scientific Ed.). 1951;40:520–525.
19. Hillery A., Park K. CRC Press; 2016. Drug Delivery: Fundamentals and Applications.
20. Lee P.I., Li J.-X. In: Oral Control. Release Formul. Des. Drug Deliv. Theory to Pract. Wen H., Park K., editors. John Wiley & Sons, Inc.; Hoboken, NJ: 2010. Evolution of oral controlled release dosage forms; pp. 21–31.
21. Yun Y., Lee B.K., Park K. Controlled drug delivery systems: the next 30 years. Front. Chem. Sci. Eng. 2014;8:276–279.
22. Zhang W., Zhao Q., Deng J., Hu Y., Wang Y., Ouyang D. Big data analysis of global advances in pharmaceutics and drug delivery 1980-2014. Drug Discov. Today. 2017;22:1201–1208.
23. Bangham A.D., Horne R.W. Negative staining of phospholipids and their structural modification by surface-active agents as observed in the electron microscope. J. Mol. Biol. 1964;8 doi: 10.1016/S0022-2836(64)80115-7.
24. Bangham A.D., Standish M.M., Watkins J.C. Diffusion of univalent ions across the lamellae of swollen phospholipids. J. Mol. Biol. 1965;13
25. Shen J., Burgess D. In: Drug Deliv. Fundam. Appl. Hillery A., Park K., editors. CRC Press; New York: 2012. Long acting injections and implants; pp. 73–91.
26. Birrenbach G., Speiser P.P. Polymerized micelles and their use as adjuvants in immunology. J. Pharm. Sci. 1976;65:17 63–1766.
27. Couvreur P., Tulkens P., Roland M., Trouet A., Speiser P. Nanocapsules: a new type of lysosomotropic carrier. FEBS Lett. 1977;84:323–326.
28. Park K. Drug delivery of the future: chasing the invisible gorilla. J. Contr. Release. 2016;240:2–8.
29. Ye M., Kim S., Park K. Issues in long-term protein delivery using biodegradable microparticles. J. Control. Release Off. J. Control. Release Soc. 2010;146:241–260.
30. Park K. Controlled drug delivery systems: past forward and future back. J. Contr. Release. 2014;190:3–8.

31. Yun Y.H., Lee B.K., Park K. Controlled drug delivery: historical perspective for the next generation. J. Contr. Release. 2015;219:2–7.
32. Rahman H.S., Othman H.H., Hammadi N.I., Yeap S.K., Amin K.M., Samad N.A., Alitheen N.B. Novel drug delivery systems for loading of natural plant extracts and their biomedical applications. Int. J. Nanomed. 2020;15:2439–2483.
33. Vincy A., Mazumder S., Amrita, Banerjee I., Hwang K.C., Vankayala R. Recent progress in red blood cells-derived particles as novel bioinspired drug delivery systems: challenges and strategies for clinical translation. Front. Chem. 2022;10
34. Patil P.B., Datir S.K., Saudagar R.B. A review on topical gels as drug delivery system. J. Drug Deliv. Therapeut. 2019;9
35. Hanley T., Vankayala R., Lee C.-H., Tang J.C., Burns J.M., Anvari B. Phototheranostics using erythrocyte-based particles. Biomolecules. 2021;11 doi: 10.3390/biom110 50729.
36. Wang C L.Z., Sun X., Cheng L., Yin S., Yang G., Li Y. Multifunctional theranostic red blood cells for magnetic-field-enhanced in vivo combination therapy of cancer. Adv. Mater. 2014;26:4794–4802.
37. Jiawei Chen L.H. Nanoscale delivery system for nutraceuticals: preparation, application, characterization, safety, and future trends. Food Eng. Rev. 2020;12:14–31.
38. Zinger A., Cooke J.P., Taraballi F. Biomimetic nano drug delivery carriers for treating cardiovascular diseases. Nanomed. Nanotechnol. Biol. Med. 2021;33
39. .Gao C., Chu X., Gong W., Zheng J., Xie X., Wang Y., Yang M., Li Z., Gao C., Yang Y. Neuron tau-targeting biomimetic nanoparticles for curcumin delivery to delay progression of Alzheimer's disease. J. Nanobiotechnol. 2020;18:71.
40. Mamo T., Moseman E.A., Kolishetti N., Salvador-Morales C., Shi J., Kuritzkes D.R., Langer R., Von Andrian U., Farokhzad O.C. Emerging nanotechnology approaches for HIV/AIDS treatment and prevention. Nanomedicine. 2010;5:269–285.

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