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Nanoparticle for Enhanced Topical Drug Delivery: An Overview of Advances, Application and Future Prospects

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ABSTRACT

Topical drug delivery systems based on nanoparticles represent a groundbreaking advancement in the field of dermatology and transdermal medication delivery. These systems utilize microscopic carriers such as solid lipid nanoparticles, and polymeric nanoparticles to transport drugs more effectively through the skin. Nanoparticles have garnered significant attention due to their unique ability to enhance drug solubility, stability, and bioavailability. By dissolving, entrapping, encapsulating, or binding the drug, nanoparticles ensure that the active pharmaceutical ingredients are delivered in a controlled and efficient manner. Their nanoscale size, typically ranging from 1 to 1000 nanometres, allows them to penetrate the skin's barrier more easily than conventional formulations, enabling deeper and more targeted delivery of therapeutic agents. One of the key advantages of nanoparticle-based delivery systems is their ability to improve the permeation of drugs through the stratum corneum, the outermost layer of the skin, which is often a significant barrier to effective drug absorption. Furthermore, the versatility of nanoparticles allows for the incorporation of both hydrophilic and hydrophobic drugs, making them suitable for a wide range of therapeutic agents. For instance, solid lipid nanoparticles and polymeric nanoparticles are better suited for lipophilic compounds. These nanoparticles' tiny size makes it possible for medications to more easily permeate the skin, improving the treatment of diseases. They also aid in regulating the drug's release, which lessens adverse effects and enhances outcomes. Furthermore, nanoparticles can be engineered to target certain skin regions, improving the accuracy of treatments.

Keywords: Nanoparticle, topical drug delivery, Novel approach.

INTRODUCTION

A drug delivery system (DDS) is a formulation or apparatus that improves safety and efficacy by controlling the location, timing, and rate of drug release in the body. The medication is administered, its active ingredients are released, and they are then transported to the site of action across biological membranes[1].

A NOVEL DRUG DELIVERY SYSTEM:

The development of innovative drug delivery methods has drawn more attention in recent years. The effectiveness, safety, and general performance of existing medications are improved by developing a new delivery system. The overall therapeutic benefit and patient compliance are important. By overcoming obstacles including partial or total degradation prior to reaching the site of action, novel drug delivery systems can increase bioavailability over time and achieve pulsatile or gastro-resistant administration.[2].

Over the past 20 years, advancements in drug formulation have deepened our understanding of drug movement through tissues. While topical drugs have long treated skin conditions, systemic drug delivery through the skin is a newer concept. Oral drug delivery systems face limitations like first-pass metabolism and pre-systemic clearance, prompting the development of alternative methods. These innovations aim to improve efficacy and reduce side effects[3].

Topical delivery involves applying medication to the skin to target cutaneous conditions or symptoms. The stratum corneum, the skin's outermost layer, acts as the primary barrier to drug penetration. While it limits the entry of many substances, strategies like permeation enhancers or nanocarriers are used to improve drug delivery. This method allows localized treatment with minimal systemic effects[4].

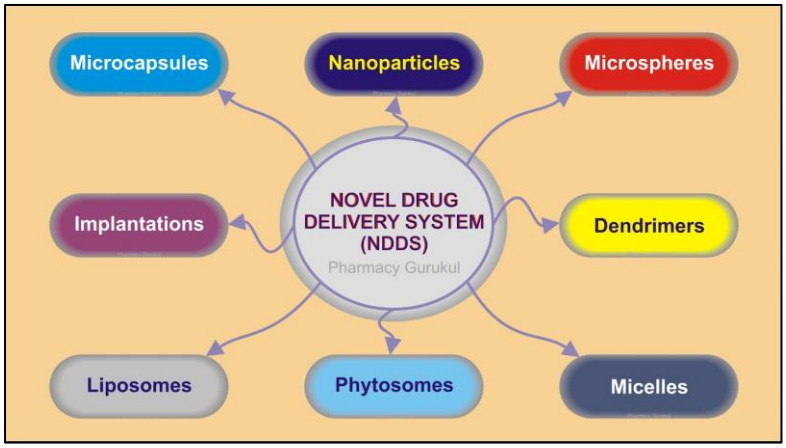

Figure 1 : Novel drug delivery system.

TOPICAL DRUG DELIVERY SYSTEM:

The skin is the largest organ in the human body. Drugs can be applied topically or transdermally through the skin to treat or prevent diseases, including systemic and dermatological issues. The outermost layer of skin tissue, known as the stratum corneum (SC), acts as a barrier between the human body and the outside world. The SC is the main barrier preventing topical medications and cosmetics from penetrating[5].Developing a topical administration system requires careful consideration of both the active principle and the medium used to provide the medication. Barriers may limit access to effective areas[6].

FACTORS AFFECTING TOPICAL ABSORPTION OF FORMULATIONS [7]

Physiological Factors

- Skin thickness.
- pH of the skin.
- Skin Hydration.
- Skin Inflammation.
- Lipid content.
- Blood flow
- Hair follicle density.
- Sweat gland density.

Physiochemical Factors

- Partition coefficient.
- Molecular weight (<400 Dalton)
- Degree of ionization (only unionized drugs gets absorbed well).
- Effect of vehicles.

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ADVANTAGES OF TOPICAL DRUG DELIVERY:[8]

- Avoidance of first pass metabolism.
- Simple and easy to use.
- Avoid risk.
- Changes in pH, the presence of enzymes, the time it takes for the stomach to empty,
- and other absorption issues are some of the drawbacks of intravenous therapy.
- Achieve efficacy with a lower total daily drug dosage by continuous drug intake.
- Avoid fluctuations in medication levels between and within patents.

DISADVANTAGES OF TOPICAL DRUG DELIVERY:[9]

- Poor permeability of some drug through skin.
- Skin irritation on contact dermatitis.
- Drug of large particle size not easy to absorb through the skin.
- Possibility of allergic reactions.

SKIN ANATOMY:

The skin is the biggest organ in the body. It consists of three laps. The outermost layer is called the epidermis; the middle layer is called the dermis; and the innermost layer is called the hypodermis.

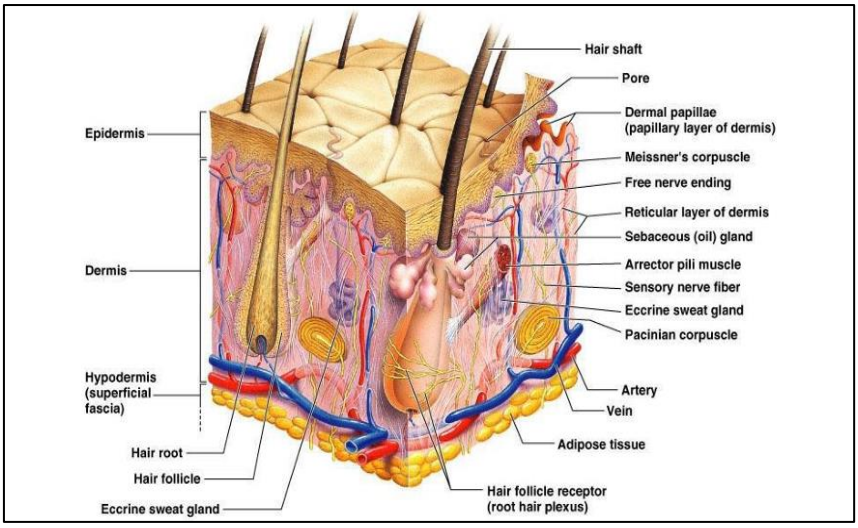

Figure 2 :Anatomy of skin

1. Epidermis: The epidermis is composed of cells known as epithelium. Among these cells are both living and dead cells. These new cells divide quickly close to the base of the epidermis, pushing the older cells upward. The epidermis does not receive its

nutrients directly from blood vessels. It receives its food by the diffusion of vital molecules from the vast circulatory network of the basal dermis[10].

2.Dermis: Dermis is the layer of skin just beneath the epidermis which is 3 to 5 mm thick layer and is composed of a matrix of connective tissues, which contains blood vessels, lymph vessels, and nerves. The cutaneous blood supply has essential function in regulation of body temperature. It also provides nutrients and oxygen to the skin, while removing toxins and waste products. Capillaries reach to within 0.2 mm of skin surface and provide sink conditions for most molecules penetrating the skin barrier[11].

3.Hypodermis: The hypodermis is the lowest layer of the skin. The skin layer comes into contact with the body's deeper tissues, such as the muscles and bones. The dermis has sweat glands, sebaceous glands, and hair follicles, despite the epidermis covering them. Sweat glands leave a thin layer of salt solution on the skin's surface. By cooling the skin, this fluid's evaporation regulates its temperature. Pleasurable feelings are produced by several glands in the body. Sweating is influenced by temperature, skeletal muscle activity, and emotions[12].

PURPOSE OF THE TOPICAL PREPARATION[13]

To create a topical medication that is both effective and efficient, the intended purpose must be considered. This has a direct bearing on the location of action and the anticipated impact of the preparation.

The following uses are possible for topical medications:

Surface effects: Antibacterial (reduction of infection), cosmetic (improvement of look), cleansing (removal of dirt and germs), and protective (prevention of moisture loss, sunscreen).

Stratum corneum effects: keratolytic (a skin shedding that helps treat psoriasis), protective (moisturising), and protective (such as sunscreens that penetrate this layer).

Viable dermal and epidermal effects: a few medication types, including anaesthetics, anti-inflammatory, antipruritic, and antihistamines, may reach these layers. Drugs can diffuse into the systemic circulation once they reach the dermis, despite the stratum corneum being difficult for them to permeate. Formulating a medication that solely has a local effect without subsequent blood absorption is challenging.

Systemic effects: a few medications, including oestradiol, nitro-glycerine, clonidine, and scopolamine, have been designed to produce systemic effects.

Effects on the appendages: Certain pharmacological classes such as antibacterial, exfoliant, depilatory, and antiperspirant are made to work on certain skin regions. One Infection is a major cause of morbidity and mortality for burn victims after the shock period. To reduce the risk of wound infection and the subsequent sepsis, early excision and the use of topical antimicrobial creams, such as silver sulphadiazine, are recommended whenever possible. Patients who have suffered severe burns may develop both cutaneous and systemic infections.

NANOPARTICLE DRUG DELIVERY SYSTEMS:

The term "nanotechnology" describes a new scientific discipline that involves the creation of different nanomaterials. Objects that range in size from 1 to 100 nm and may differ from the bulk material due to their size are known as nanoparticles. Currently, copper, zinc, titanium, magnesium, gold, alginate, and silver are used to create various metallic nanostructures. Nanoparticles have a wide range of applications, including medicinal treatments, industrial manufacturing in solar and oxide fuel batteries for energy storage, and widespread integration into many daily products like clothing and cosmetics[14].

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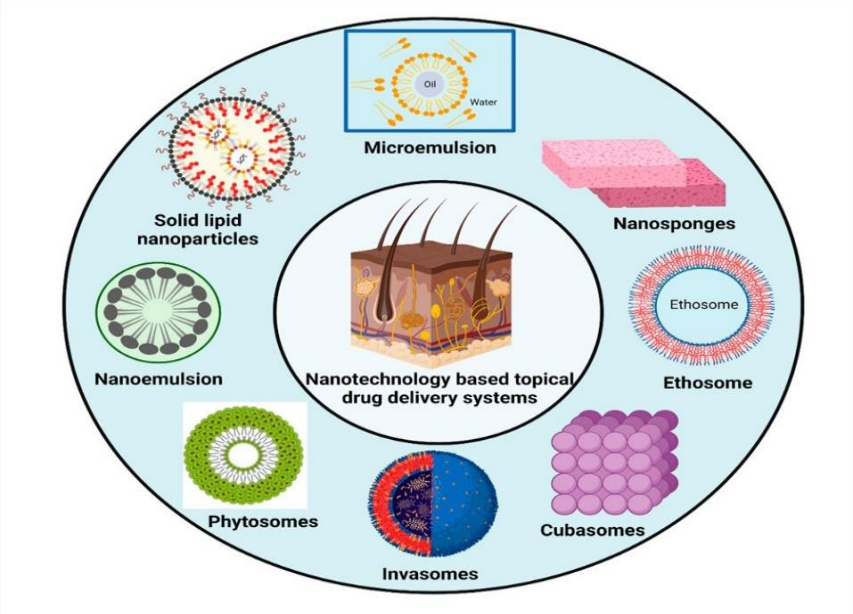

Figure 3 : Novel approaches

Small particles are known as nanoparticles (NPs). Their active substances are dissolved, trapped, and/or encapsulated in nanomolecular structures. NPs are currently present in hundreds of consumer goods, from processed food items to sunscreen and air conditioners. NPs have become more well-known in the medical community over the last few decades as a successful drug delivery and therapeutic method [15].

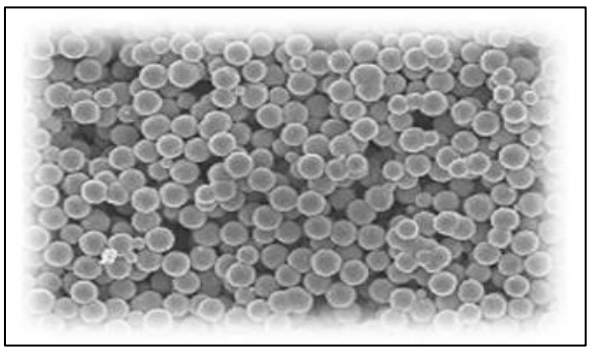

Figure 4 :Nanoparticles

Nanoparticles traits such as particle size, surface charge and shape play important roles in creating effective nanoparticles delivery systems that function through a variety of mechanisms. In vivo, they protect drugs in systemic circulation, target specific sites, and ensure controlled, sustained delivery to the action site. This minimizes side effects and improves drug efficiency. The drug must remain active and effective at appropriate concentrations while in circulation[16]. Solubility enhancement of poorly water-soluble drugs is a crucial issue to improve solubility and bioavailability. Numerous attempts to improve the dissolution behaviour have been made by using solid dispersions of drugs with polymers, inclusion complexes with cyclodextrins, liposomes, emulsions, and microemulsions[17].

For pharmaceutical applications, nanoparticle engineering techniques have been created and documented to speed up the dissolving of poorly soluble medications, potentially resulting in significant increases in bioavailability. Poorly soluble medications can now be made as particles or in combination with other pharmaceutical excipients thanks to nanoparticle engineering[18].

A few characteristics of medication delivery system using nanoparticles [19]

- Easy and affordable to scale up and manufacture.

- They and prepared without the use of heat, strong shear, or organic solvents.
- Stable and reproducible.
- Suitable for a wide range of medication, including proteins, polynucleotides, and small compounds.
- Capacity for lyophilization.
- After administration, stable.
- Non-toxic.

Benefits of nanotechnology in healthcare [20]

- Enhanced bioavailability and stability of ingredients.
- Extended shelf life.
- Targeted delivery of ingredients to a specific cell type or receptor.
- Extended release of ingredients for a longer therapeutic effect.
- Capable of heat-triggered local release.
- Helpful in diagnosing a variety of diseases.
- Minimise drug side effects.

ADVANTAGES OF NANOPARTICLES: [21]

- Nanoparticles have many benefits for drug delivery systems. Among these benefits are, Nanoparticles offer numerous noteworthy benefits over conventional and traditional drug delivery methods.
- They improve the blood circulation, bioavailability, and therapeutic efficiency of drugs while decreasing Several methods, such as oral, nasal, parenteral, intraocular, etc., can be used to give nanoparticles.
- When compared to other dosage forms, nanoparticles exhibit superior drug delivery in the minuscule regions of the body and can target specific cell types or receptors.
- Because of their small size, nanoparticles can readily pass through the body's physiological barriers and enter cell walls, blood vessels, the stomach epithelium, and the blood–brain barrier.
- Nanoparticles increase a poorly soluble drug's aqueous solubility, increasing the drug's bioavailability.
- As a targeted drug carrier, nanoparticles improve effective drug distribution and lessen drug toxicity.

POLYMERS USED IN PREPARATION OF NANOPARTICLES:[22]

The polymers should be compatible with the body in the terms of adaptability (non-toxicity) and (non-antigenicity) and should be biodegradable and biocompatible.

Natural polymers*:* The most commonly used natural polymers in preparation of polymeric nanoparticles are

- Chitosan
- Gelatin
- Sodium alginate
- Albumin

There are many synthetic polymers like

- Polylactides(PLA)
- Polyglycolides(PGA)
- Poly(lactide co-glycolides) (PLGA)
- Polyanhydrides
- Polycaprolactone
- Poly glutamic acid
- Poly malic acid
- Poly(N-vinyl pyrrolidone)
- Poly(methyl methacrylate)
- Poly(vinyl alcohol)

MECHANISMS OF DRUG RELEASE [23]

One of the three general physico-chemical methods can be used by the polymeric drug carries to deliver the drug to the tissue location.

- Through hydration, which causes the polymer nanoparticles to enlarge, and diffusion which releases them.
- Through an enzymatic reaction that causes the polymer to rupture, cleave, or degrade at the delivery point, releasing the medication from the inner core that is imprisoned.
- The drug's dissociation from the polymer and its release or dead sorption from the enlarged nanoparticles.

METHOD OF PREPARATION FOR NANOPARTICLE[24]

There are numerous methods for creating nanoparticles. A polymer matrix, a nanoparticle core, a chemically bound polymer shell, or adsorption on the particle surface are some of the ways that drugs might be encased.

EMULSION SOLVENT EVAPORATION METHOD:

Emulsification solvent evaporation is a process for producing nanoparticles. Although commonly employed for encapsulating hydrophobic medicines, it does not work well for integrating hydrophilic bioactive substances. The polymer is evaporated and dissolved in organic solvents like chloroform, ethyl acetate, or methylene chloride before being emulsified in an aqueous phase with a stabiliser (e.g., PAV). After forming the nano-emulsion, the solvent diffuses into the outer phase until saturated. Solvent molecules evaporate at the water-air contact, causing diffusion from the emulsion's inner droplets to the outer phase. At the same time, the precipitation of the polymer leads to the formation of nanospheres.

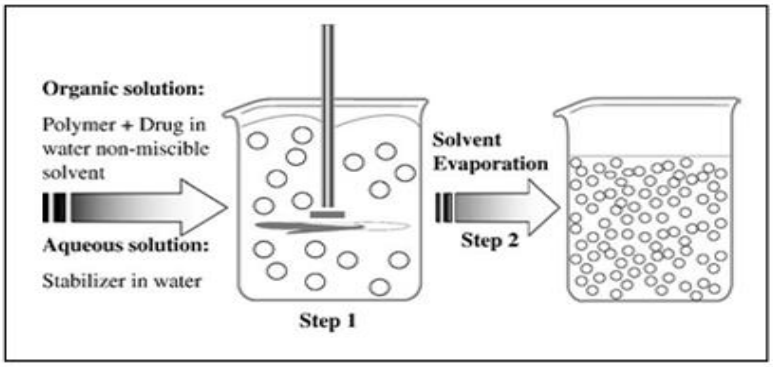

Figure 5 : Schematic representation of the solvent-evaporation technique

NANOPRECIPITATION METHOD:

Nanoprecipitation can be used to create nanoparticles. Using a magnetic stirrer, the polymer and medication are combined in an aqueous solution of the surfactant after being dissolved in acetone, ethanol, or methanol. The medicine and polymer precipitate after the organic solvent instantly diffuses into the outer aqueous phase. The solvent is eliminated and the suspension is concentrated at lower pressure once the nanoparticles have formed. This approach has the benefit of not requiring the use of a surfactant; yet, it is only applicable to medications that are very soluble in polar solvents.

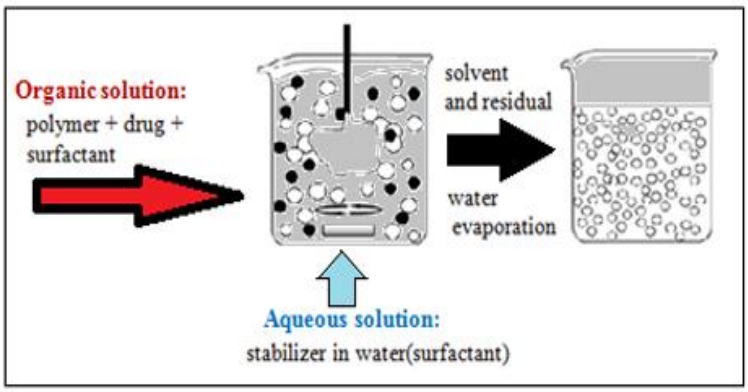

Figure 6 : Schematic representation of the nanoprecipitation technique.

SALTING-OUT METHOD:

Another technique for producing nanoparticles is the salting out approach. This method, which is based on the precipitation of a hydrophobic polymer, can be used to encapsulate either hydrophilic or hydrophobic drugs because it allows for the removal of certain drugs using a variety of solvents, including polar (like acetone or methanol) and non-polar (like acetone or methanol) as well as non-polar (like methylene or chloroform).

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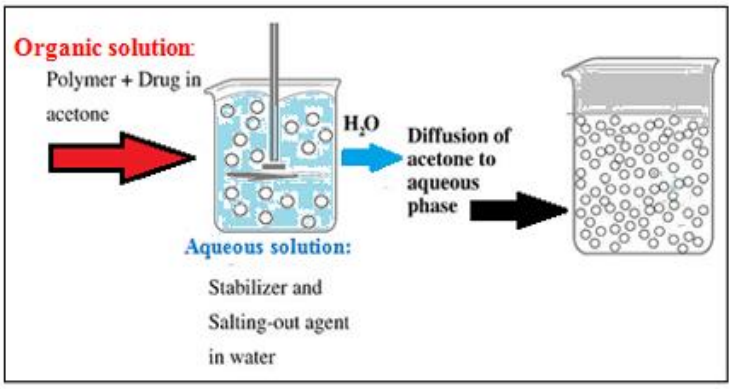

Figure 7 :Schematic representation of the salting out technique

COACERVATION OR IONIC GELATION METHOD: [25]

Biodegradable hydrophilic polymers like sodium alginate, gelatin, and chitosan are used in the production of nanoparticles. The polymer chitosan, di block copolymer ethylene oxide or propylene oxide (PEO-PPO), and a poly anion sodium tripolyphosphate are the two aqueous phases that are mixed together in this process. This process creates coacervates that are about nanometres in size by joining positively and negatively charged chitosan. Coacervates are created when two aqueous phases interact electrostatically, but ionic gelation is when a material changes from a liquid to a gel because of ionic interaction at room temperature settings.

EMULSIFICATION / SOLVENT DIFFUSION METHOD :

This process involves liquefying the polymer in a solvent that dissolves in water and then saturating it with water. An aqueous solution with a stabiliser is used to emulsify the solvent phase of the polymer that has been soaked in water. The solvent is then removed using filtration or evaporation.

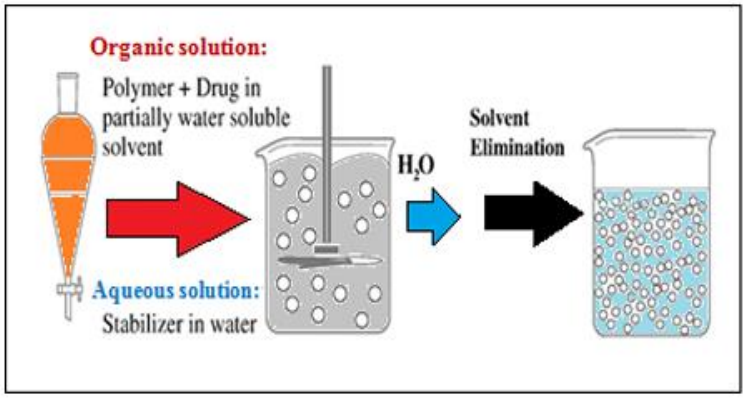

Figure 8 :Schematic representation of the emulsification/solvent diffusion technique

EVALUATION OF NANOPARTICLES:

1. Zeta potential:[26]

Zeta potential was measured by the zetasizer. For this purpose, the colloidal suspensions were diluted with distilled water and placed in the zetasizer chamber.

2. Particle size: [27]

The two most crucial aspects of nanoparticle systems are particle size and size distribution. They ascertain the nanoparticle system's toxicity, targeting capability, biological destiny, and in vivo distribution. They can also affect the stability, drug loading, and drug

release of nanoparticles. At the moment, dynamic light scattering or photon-correlation spectroscopy are the most common and quick ways to measure particle size. Scanning or transmission electron microscopy is typically used to validate the results of photon-correlation spectroscopy.

3. *In-vitro* drug release studies:[28]

In vitro drug release profile was performed by using dialysis bag method with the help of dialysis membrane molecular weight cut off 12000-14000 Da. The release rate of drug from formulation depends on various factors like polymer ratio, polymer degradation or erosion, solubility. In study the present nanoparticles dispersion was filled in the dialysis tube and immersed in Phosphate saline buffer (pH 7.4) under continuous magnetic stirring and the temperature should be maintained at 37±1ºC throughout the procedure. At specific time intervals, the samples were taken and diluted to determine the concentration UV spectrophotometer at 307nm.

4. Stability of nanoparticles:[29]

Stability studies of prepared nanoparticles determined by storing optimized formulation at 4°C ±1°C and 30°C ± 2°C in stability chamber for 90 days. The samples were analysed after a period like at 0, 1, 2, and 3 months for their drug content, drug release rate as well as any changes in their physical appearance.

5. Drug entrapment efficiency:[30]

The encapsulation efficiency and loading capacity of the nanoparticles were determined by the separation of nanoparticles from the aqueous medium containing non-associated by cold centrifugation (Eppendorf Centrifuge. The amount of drug in the supernatant was measured by UV-Visible Spectrophotometer. The entrapment efficiency (%) of drug was calculated by the following equation;

$$Entrapment\ efficiency\ (\%) = \frac{\text{Initial amount of drug added} - \text{Amount of drug actually present} \times 100}{\text{Initial amount of drug Added}}$$

6. Drug-excipient compatibility studies: [31]

The drug excipient compatibility studies were performed by using FT-IR spectrophotometer. The FT-IR spectra of drug, polymers, and formulations were analysed separately and then correlated for incompatibility.

7. Differential Scanning Calorimeter (DSC) [32]

DSC studies were carried out on DSC Q60. Sealed and perforated aluminium pans were used in the experiments for all samples. Temperature calibrations were performed using indium as standard. An empty pan sealed in the same way as for the sample was used as a reference. The entire samples were run in nitrogen atmosphere at a scanning rate of 10° C/ min from 50-300°C. By comparing the DSC curves of a pure drug sample with that of formulation, the presence of an impurity can be detected in a formulation.

8. Viscosity[33]

Using a Brookfield viscometer, the viscosity of the solid lipid nanoparticle gel was measured. The gel's temperature was held constant at 25°C. The viscometer was attached to the Helipath T-bar Spindle No. 05, which was then submerged in a beaker containing 25 g of SLN gel. The viscometer was run at various revs, and the reading in centipoises (cps) was recorded.

9. In-vitro release kinetics study: [34]

In order to analyse the drug release mechanism, in vitro release data were fitted into a zero order, first order, Higuchi, and Korsmeyer-peppas model. Zero order kinetics: The zero order rate equation describes the systems where the drug release rate is independent of its concentration.

$$Q1 = Q0 + K0\ t$$

First order kinetics: The first order equation describes the release from a system where the release rate is concentration dependent. Kinetic equation for the first order release is as follows:

$$\text{Log } Qt = \log Q0 + K1\ t/2.303$$

Higuchi model: describes drug release as a diffusion process based in the Fick's law, square root time dependent.

$$Qt = KH\ t1/2.$$

APPLICATIONS OF NANOPARTICLE DELIVERY SYSTEMS [35]

- **Targeting drug delivery by encapsulation**

Nanoencapsulation improves drug stability, bioavailability, and targeted delivery by preventing degradation and increasing tissue absorption. It increases retention period and intracellular penetration, improving therapeutic efficacy. Successful encapsulation of bioactive substances has resulted in increased regulated release and bioactivity. Effective nanomedicine is dependent on the choice of polymers (e.g., PLA, PLGA, chitosan) for high encapsulation efficiency and customised drug release.

- **Nanoparticles for drug delivery into the brain**

The blood-brain barrier (BBB) limits drug delivery to the central nervous system due to impermeable endothelial cells with tight junctions, enzymatic activity, and efflux transport mechanisms. Water-soluble medicines are blocked, although lipophilic and tiny molecules can pass through selectively. This selectivity is a significant challenge in designing CNS medicines. Overcoming the BBB is critical for the successful treatment of neurological diseases.

- **Nanoparticles for ophthalmic delivery**

In ocular treatments, nano formulations improve the solubility and effectiveness of poorly soluble drugs by prolonging their residence time in the cul-de-sac, which is essential for treating eye disorders. They enhance medication delivery and preserve ocular tonicity. Fluid intake and outflow cause lachrymal fluid dynamics to fluctuate constantly, affecting the solubility and rate of dissolution. This fluctuation impacts the drug's inherent rate of dissolution.

- **Topical formulations**

Drug nanoparticles can be mixed into creams and waterless ointments. The nanocrystalline form increases the drug's saturation solubility in topical dose form, allowing for better drug diffusion into the skin. Micellar nanoparticles are a technique suitable for topical applications. This method permits high quantities of drugs to permeate the skin, forming a drug depot in the stratum corneum and epidermis.

- **Cosmetic applications [36]**

Solid lipid nanoparticles (SLNs), made from physiological lipids, offer occlusive and UV-protective properties, making them suitable for cosmetics. Their occlusiveness enhances skin hydration and permeability through the stratum corneum. SLNs provide physical sun protection by effectively scattering and reflecting UV light due to their particle size and refractive index. They outperform liquid emulsions in light scattering, offering better UV defences.

- **Diagnostic Delivery [37]**

Early and precise disease diagnosis is crucial for effective treatment, utilizing imaging modalities like MRI, CT, PET, and fluorescent imaging. Nanoparticle-based approaches, such as liposomes and polymeric micelles, enhance imaging signals at disease sites for accurate detection. While these methods improve in vitro imaging capabilities, achieving targeted in vivo delivery remains a significant challenge. Overcoming this limitation is key to advancing diagnostic and therapeutic applications.

RECENTLY REPORTED NANOPARTICLE FORMULATION

SL. NO	AUTHOR NAME	METHOD	DRUG	REPORT
1	Farid *et al*., (2020),	Ionic gelation technique.	Ofloxacin	An ofloxacin loaded chitosan nanoparticles against E.coli and S.aureus showed Minimum Inhibitory Concentration nanoparticles could be applied as carrier for decreasing the dose of antibacterial agents in the infection.[38]
2	Akbari *et al*., (2021),	Ionic gelation technique	Salicylic acid	The Salicylic acid Nano particles were more cytotoxic than salicylic acid. These data demonstrated that the drug release. mechanism governed by Korsmeyer Peppas model[39]
3	Akther *et al*., (2021),	Emulsion diffusion evaporation technique	α-mangostin	The formulated Poly Lactic Glycolic Acid Nano Particles were converted into a preformed Carbopol gel base it had a significant cytotoxic effect and antioxidant effect.[40]
4	Sadozai *et al*., (2022),	Emulsion/ solvent evaporation method	Ketoconazole	The optimised formulation with better bioadhesive property may improve the bioavailability of topical administration.[41]
5	Sachith *et al*., (2022),	Ionic gelation technique.	Ezetimibe	This chitosan- based delivery system opens new and interesting perspectives as drug carriers. because There was a steady decrease in the entrapment efficiency on increasing the polymer concentration in the formulations.[43]
6	Sufiyan Ahmad *et al* .,(2023)	Emulsification-diffusion method	Econazole nitrate	The emulsification-diffusion method produced stable Econazole nitrate loaded nanogels, with exhibiting the best stability and amorphous drug transformation. The formulation achieved good drug release with excellent viscosity and spreading properties.[44]
7	Ahmad M. *et al*.,(2023)	Self-emulsifying technique	Miconazole nitrate	The optimized formulation with Carbopol showed the highest drug release and effective penetration. Antifungal tests against *Candida albicans* revealed significantly larger inhibition zones for the nanoemulgel.[45]
8	Yallavula J *et al*.,(2023)	Solvent diffusion method	Luliconazole	A topical luliconazole SLN gel formulation with improved entrapment efficiency and prolonged drug release. Fungal infections can be effectively treated with the optimised gel because it showed excellent antifungal activity against Candida albicans.[46]
9	Fiza Farheen *et al* .,(2024)	Emulsification-ultrasonication technique	Efinaconazole	The formulated nail gel successfully enhances the localized action and adherence of Efinaconazole, making it effective for treating nail disorders like onychomycosis. Efinaconazole complements the formulation by providing broad-spectrum antifungal activity. [47]
10	O M Kolawole *et al*.,(2024)	Emulsification method	Fluconazole	The formulation focused on developing fluconazole emulgels using xanthan gum and HPMC E5LV for vaginal candidiasis treatment. the study highlights the potential of fluconazole emulgels as a viable therapeutic option for vaginal candidiasis. [48]

Future of nanoparticles as drug delivery systems [49]

When compared to conventional drug delivery methods, nanoparticles provide numerous benefits. However, additional in vivo research and clinical trials are required to comprehend the toxicity and long-term biological behaviour of nanoparticles before they may be used more widely in the pharmaceutical industry.

Recently, an increasing number of studies have focused on surface modification of nanoparticles to extend their retention period. Polyethylene glycol is a prominent alternative for nanoparticle surface modification. When grafted to the surface of nanoparticles. The creation of a hydrated layer on the nanoparticles can aid to extend their circulation duration following intravascular injection. Another top-down biomimetic technique, cell membrane coated nanoparticles, has been extensively studied.

Another rapidly developing area of study is the creation of multifunctional nanoparticles. The expanding medical demands are the driving force behind this field. In addition to delivering medications, nanoparticles are required for drug monitoring and detection during cancer treatment.

Conclusion:

Nanoparticle-based topical drug delivery systems have emerged as a promising approach to enhance drug penetration, bioavailability, and therapeutic efficacy. These nano-systems offer controlled and sustained drug release while minimizing systemic side effects, making them ideal for treating localized skin disorders. The selection of suitable nanoparticles, such as, solid lipid nanoparticles, and polymeric nanoparticles, plays a crucial role in optimizing drug stability, permeability, and retention time. Despite their advantages, challenges such as formulation stability, large-scale production, and regulatory concerns need to be addressed for their widespread clinical application. Continued research and advancements in nanotechnology will further improve the effectiveness and commercial viability of nanoparticle-based topical drug delivery systems, paving the way for innovative dermatological and topical treatments.

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