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Solid Liquid Nano Particle for a Cosmetic Active Delivery System a Review

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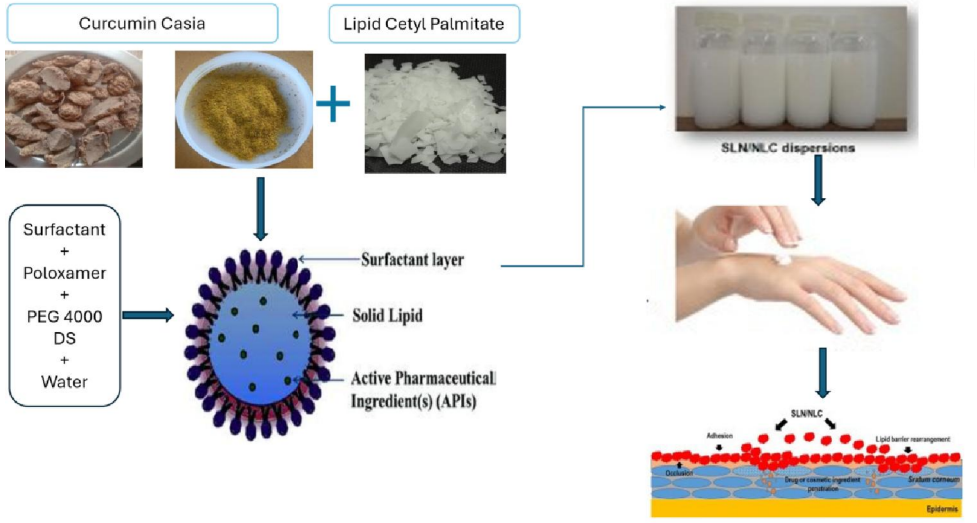
Abstract: *The demand of cosmeceutical science upsurges as the expectation of consumers is to get beauty and therapeutic benefits in a single regime or in a one product. This can be fulfilled by introduction of modern nano drug delivery systems like Solid lipid nanoparticles (SLN). Dermo cosmetics disorders such as ageing, wrinkled skin, pigmentation, acne, eczema, UV radiation damage, stress, psoriasis etc. can be treated with transdermal delivery system. A modern delivery system like SLN can administer active cosmetics compounds to the target skin layers while minimizing side effects hence it is worth reviewing the ability of Solid lipid nanoparticles (SLN) to demonstrate skin penetration.*
SLN is a novel delivery system for cosmetic and pharmaceutical actives and this paper highlights advantages of SLN for cosmetic applications. This review is an attempt to compile the findings from key research related to key drug delivery systems like SLN. The study further discusses the role of SLN, its mechanism and impact on dermo cosmetics with inherited advantageous properties which is to be used for dermal applications including ability to provide solution for skin related problems.

Keywords: Solid Liquid Nanoparticle, Cosmetic Dermatology, Nanoparticles, Nanocarriers, Nanoemulgel, Ethosomes, Liposomes, Organogels, Green Nanotechnology, Topical Delivery Systems.



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I. INTRODUCTION

Nanoparticles of solid lipids (SLN) introduced for the first time in December 1991 to be a system of medication carriers to what called traditional colloidal carriers, that system that includes nanometre ranges of spherical stable lipid cells, which are often scattered in fluid surfactant arrangements or in water [1].

Lipid nanoparticles with solid particle matrix are derived from oil in water emulsions by simply replacing the liquid lipid (oil) with a solid lipid, i.e. being solid at body temperature. The first generation of solid lipid nanoparticles (SLN) was developed at the beginning of the nineties [1,2]. They were produced from solid lipids only. In the second-generation technology of the nanostructured lipid carriers (NLC), the particles are produced by using a blend of a solid lipid with a liquid lipid, this blend also being solid at body temperature. By preparing the particles from a solid lipid, especially highly purified solid lipids, the particle matrix tends to form a relatively perfect crystal lattice leaving limited space to accommodate the active (Figure. 2). This limits the loading capacity and can lead to expulsion of active from the lipid matrix during storage [2]. In contrast, the use of a lipid mixture with very differently structured (sized) molecules distorts the formation of a perfect crystal. The particle matrix contains many imperfections providing spaces to accommodate the active in molecular form or as amorphous clusters. [3] In the second half of the nineties there was an increasing interest in investigating the SLN for dermal application, especially for cosmetic use. Interesting cosmetic molecules were incorporated such as e.g. retinol and retinyl palmitate [4], vitamin E, vitamin E acetate, Retinyl acetate and coenzyme Q 10 [5]. An example for pharmaceutical actives is the incorporation of corticoids, such as prednicarbate is very well established and they have gained great attention in controlling the drug release, increasing the bioavailability and attaining a sustain release profile of entrapped drug substance [6].

At the turn of the millennium the NLC were developed which – based on the controlled nano structuring of the particle matrix which provides advantages with loading capacity and long-term stability (firm inclusion of actives, physical stability of suspension) [7]. For cosmetic applications requiring a high crystallinity of the carrier e.g. UV protection, SLN is suitable carrier. An in vivo study showed that addition of 4% SLN to a conventional o/w cream directed to an increase of skin hydration of 31% after 4 weeks. The application of SLN as physical sunscreens as active carriers for molecular sunscreens has also been investigated. The amount of molecular sunscreen could be decreased by 50% while maintaining the protection level compared to a conventional emulsion [8]. Historically at the beginning research with SLN focused on their use as intravenous/parenteral drug carrier, gradually interest shifted to lipid nanoparticles for oral administration and later for dermal application. One of the reasons is that the regulatory hurdles are lower for oral, especially for dermal products, allowing a faster introduction of the carrier system to the market. Comparing lipid nanoparticle formulations for dermal applications in the pharmaceutical and cosmetic field, there is basically little difference regarding technological aspects (e.g. incorporation of actives into particles, incorporation of particles into cream, stability in cream etc.) [9]. This article reviews the cosmetic benefits of SLN in general, and especially technological aspects and special features of the cosmetic products available by now, consideration is given to technological challenges when moving from lab scale to a large-scale production. It should be emphasized that the formulation and technological aspects have also high relevance for upcoming cosmetics products [10]. The cutaneous use of SLN has been proposed for both local and transdermal delivery the reported studies show promising results only for local application [11]. The following is a description of some common SLN and their distinctive features. Novel medication delivery and active targeting are novel strategies in cosmetics and pharmaceutical science [12]

II. METHODOLOGY

This review was conducted using a systematic approach to identify, analyze, and synthesize literature on the dermatological and cosmetic applications of SLN and its formulations.

A comprehensive literature search was performed using Google Scholar, supplemented by PubMed and ScienceDirect for peer-reviewed sources, using keywords like “Solid Liquid Nanoparticle, Cosmetic Dermatology, Nanocarriers, Nanoemulgel, Ethosomes, Liposomes, Organogels, Green Nanotechnology, Topical Delivery Systems”

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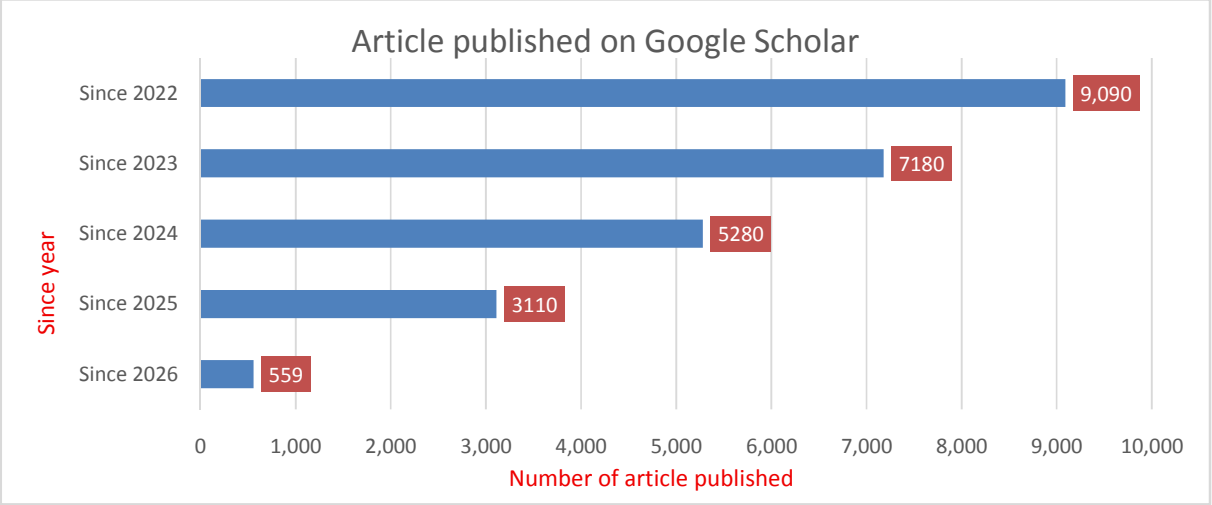
The initial broad search for SLN review yielded approximately 23,600 results. Numbers are based on aggregated Google Scholar search results for respective keywords.



Graph 1: Search Summary for SLN review (Search conducted on Google Scholar on 30 March 2026)

Advance active delivery systems

Nanotechnology-driven delivery platforms have gained significant attention for maximizing dermal and transdermal delivery of black turmeric phytoconstituents. Liposomes, composed of phospholipid bilayers, can encapsulate both hydrophilic and lipophilic compounds, improving solubility and skin deposition. Using the tools of nanotechnology, drug delivery systems within the nanometre size regime can be developed to alter both pharmacological and therapeutic effects of drug molecules. Due to their small size, these novel nanotechnologies offer superior advantages, such as altered pharmacokinetic behaviour and improved payload, over traditional large-scale systems. In addition, the relative ease in modifying their surface chemistry permits the attachment of targeting and therapeutic molecules for specific therapeutic applications. Finally, complex nanostructures can be assembled using different building blocks with multiple functionalities ranging from targeting, detecting, imaging and therapeutic capabilities [13].

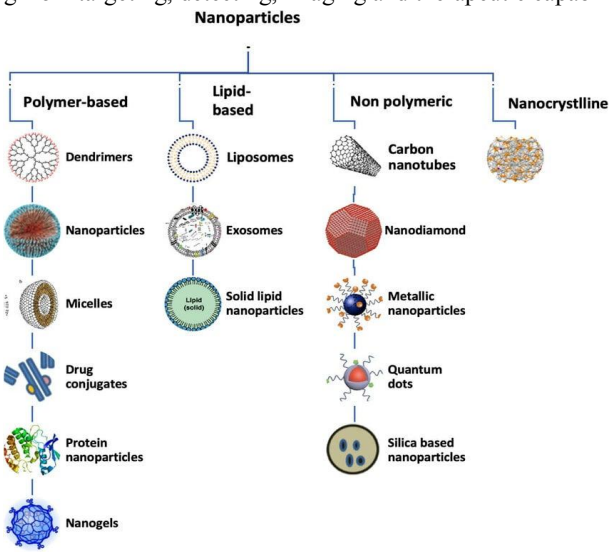


Figure 2: Advanced Drug Delivery Systems (Image taken from Google image)

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Table 1: Advanced Drug Delivery Systems [14,15]

System	Vesicle Size	Description	Skin Deposition / Retention	Advantages	References
Transferosomes	~200 nm	Ultra-deformable lipid vesicles with edge activators (Tween 20, Tween 80)	~45.9% after 24 h	Deep epidermal penetration; suitable for anti-wrinkle creams	[16]
Ethosomes	~216 nm	Lipid vesicles with high ethanol content (30–50%) for enhanced permeation	~44% after 12 h	Ethanol acts as penetration enhancer; antioxidant delivery	[17]
Invasomes	363–461 nm	Vesicles with phosphatidylcholine, ethanol, and terpenes (e.g., eucalyptol)	~942 µg/cm² retention	Highest penetration and retention; ideal for chronic skin conditions	[18,19]
Spanlastics	~212.8 nm	Elastic nanovesicles using Span® 60 and Tween® 80 for topical gels	High (confocal depth ~112.5 µm)	High entrapment efficiency (99.8%); controlled release	[20]
Organogels	Semi-solid	Gel systems using low-molecular-weight gelators (12-HSA) in triacetin	High retention	Depot effect; antibacterial activity; wound healing	[21]
Microemulsions	<200 nm	Thermodynamically stable systems with high solubilization capacity	Moderate	Enhanced solubility; risk of irritation from surfactants	[22]
Nanoemulgels	<200 nm	Nano emulsion incorporated into gel base for controlled release	High	Improved retention; sustained release; cosmetic acceptability	[23]
SLNs/NLCs	50–200 nm	Lipid-based nanoparticles for stability and occlusive effect	High	Increased drug loading; enhanced hydration	[24]
Cyclodextrin Complexes	Molecular level	Inclusion complexes to improve aqueous solubility and protect curcuminoids	N/A	Stability enhancement; easy incorporation into gels	[25]

Solid Lipid Nanoparticle (SLN)

SLN is composed of a matrix of solid lipids that are sustained in aqueous dispersion by surfactants or polymers, and the dispersion can be spray-dried or lyophilized to form a dry product [26, 27]. Solid lipid nanoparticles can combine particle shape and physical integrity with both physical and chemical stabilization of delicate components. Lipids have been proposed as an alternate carrier to circumvent the constraints of polymeric nanoparticles, notably for lipophilic medicines. Such small particles of lipids are known as solid lipid nanoparticles (SLNs), and they are gaining popularity among formulators all over the world. SLNs are colloidal carriers that were developed in the last decade as a replacement for traditional carriers (emulsions, liposomes, and polymeric nanoparticles) [28-30]. In figure 4 the Pictorial presentation of the structure of solid lipid nanoparticles is a new submicron-sized lipid emulsion in which the liquid component of lipid has been replaced with a solid lipid. SLN has unique qualities such as tiny size, large surface

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area, high drug loading, and phase interaction at interfaces, and are appealing due to their potential to improve the performance of medicines, "Nutraceuticals" and other materials [31- 33].

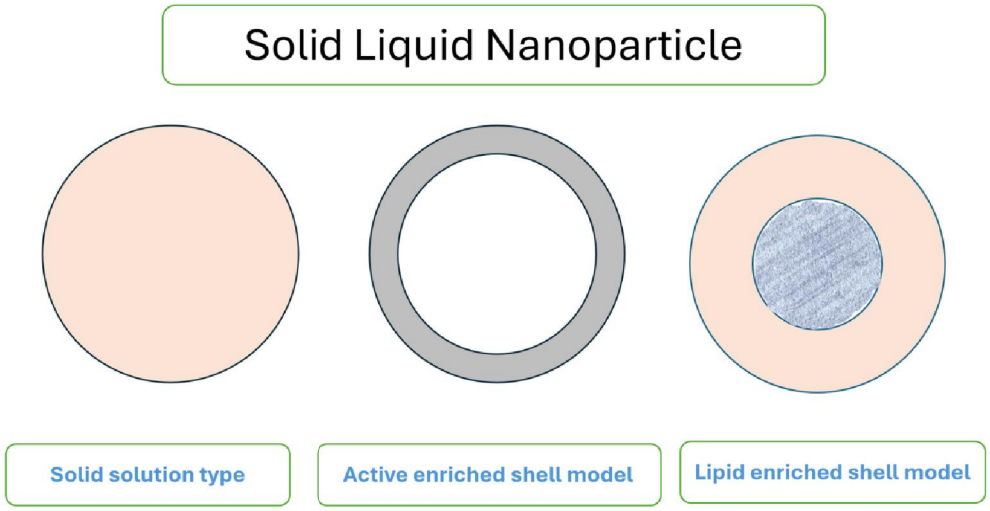

Figure 3: Structure of solid lipid nanoparticle [34-36]

Structure of SLN

SLNs are spherical in shape with a smooth surface possessing mean diameter ranging between 50 and 1,000 nm. Both in vivo and in vitro behaviors are dependent on the physicochemical characterization of SLNs. Solid lipid (at 25°C–28°C), emulsifiers for certain times simultaneously, and along with appropriate solvent for solubilizing lipid and non-lipid components, together constitute the typical SLNs in Figure 4 [37]. These SLNs work better for topical conditions. The surfactant shell model, lipid loaded core and active must crystallize much before liquid precipitate. The drug-loaded core model facilitates the sustained release of therapeutic agents and obeys Fick's law of diffusion. Highly lipophilic drugs are dispersed homogeneously within the lipid matrix employing cold homogenization. Hence, SLNs benefit in smooth production, employing simple homogenization techniques [38].

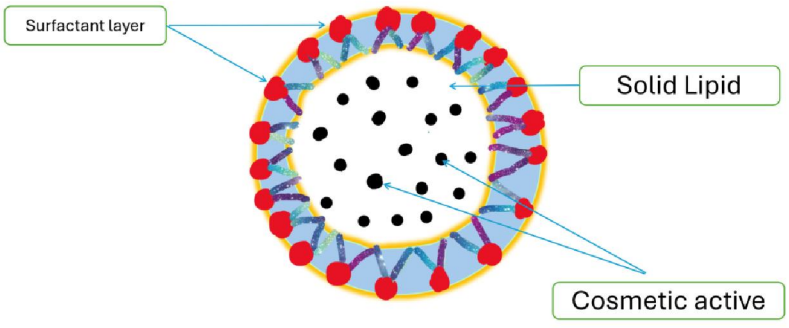

Figure 4: Structure of solid lipid nanoparticle [39-40]

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Active release through SLN

Higher active delivery is achieved by increasing surface area due to decrease in particle size in nanometre range. The partition coefficient of the medication has the inverse effect with its release mechanism. When the cosmetic active is homogeneously emulsified with lipid the control release of active is achieved [41] This can be determined by the type of entrapment in lipid system. The lipid crystalline nature and active high mobility provide quick active delivery as targeted at desired area by formulator.

SLN Formulation

Table 2: Typical SLN formulation with optimized percentage of active [42-47]

Ingredient	% (W/W)	Function
Cetyl palmitate	8	Lipid
Poloxamer 407	4	Non-Ionic Surfactant
Active - Black Turmeric Extract	5	Cosmetic Active
Polysorbate 80	1	Co-surfactant
Poly Ethelene Glycol 4000 DS	0.5	Skin Moisturizing
Glycerin	2	Humectant
Water	79.5	Solvent
Total	100	

SLN Methods of preparations [48-51]

1) High-pressure homogenization technique
2) Hot homogenization technique
3) Cold homogenization technique
4) Emulsification solvent evaporation technique
5) Microemulsion based technique
6) Supercritical fluid method
7) Spray drying method
8) Double emulsion technique

High pressure homogenization

High pressure homogenization techniques were initially used to produce solid lipid Nano dispersions [48]. High-speed homogenization method is used to produce SLN by melt emulsification [52]. Investigated the influence of different process parameters, including emulsification time, stirring rate and cooling condition on the particle size and zeta potential. The best SLN quality was obtained after stirring for 15 min at 25,000 rpm followed by cooling 10 min and stirring at 5000 rpm at a room temp. In contrast, the best conditions for Dynasan116 dispersions were a 10-min emulsification at 25,000 rpm and 5 min of cooling at 5,000 rpm in cool water [53].

Hot homogenization:

Hot homogenization is carried out at temperatures above the melting point of the lipid and is like the homogenization of an emulsion. A pre-emulsion of the drug loaded lipid melt and the aqueous emulsifier phase (same temperature) is obtained by high-shear mixing device like Silversion-type homogenizer [54].

Cold homogenization technique:

The cold homogenization is carried out with the solid lipids hence churning and milling of material is done at higher pressure [55].

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Emulsification solvent evaporation technique

In this technique oil in water emulation is carried out whereas lipid and active is added in oil phase and cyclohexane solvent is used. Aqueous phase is prepared separately and emulsification is carried out. After evaporation of solvent, SLN is form in aqueous medium by precipitation of lipid present. By this method SLN can be produced using cosmetic active with mead diameter of 50 to 100 nm [56].

Micro emulation based SLN preparation

In this process a lipid or mixture of lipid components with active material is taken in a manufacturing vessel. The material is mixed well and heated up to melting point of lipid to bring entire material at molten stage. In a separate vessel aqueous phase along with surfactant and co-surfactant is taken and heated to the same temperature of lipid mix. Once the desired temperature is attained, lipid mix is added to aqueous phase slowly under contact stirring for 30 to 45 minutes to get uniform emulsion and lipid microspheres are obtained [57].

SLN preparation using supercritical fluid method

This technique is comparatively new to manufacture SLN which is solvent less preparation which is a benefit to shorten the process. There are more variations with this technique as the powder and nanoparticle preparations [58,59]. The SLN can be obtained by rapid expansion of supercritical carbon dioxide liquid processes. [60].

SLN reparation by spray drying method

In this technique aqueous SLN dispersion is converted in to free flowing dry powder by spray dying method which employs atomising the liquid feed in to dry air their by evaporating solvent quickly and getting solid particles the equipment used are feed system like tank with pump, atomizer nozzle, drying chamber, cloth filter for powder separation, fluid bed dryer, air handling unit and exhaust. A uniform SLN particle us obtained by spray drying technique [60].

Double emulsion technique

For the preparation of hydrophilic loaded SLN, a novel method based on solvent emulsification-evaporation has been used [61]. Here the drug is encapsulated with a stabilizer to prevent drug partitioning to external water phase during solvent evaporation in the external water phase of water in oil in water system of double emulsion is established.

Table 3: Manufacturing process [38,62-68]

Sl. No	Manufacturing Process	Time
1	All water-soluble material is taken in a mixer and mix well and heated to 78^{O} C	45 Min
2	All oil and lipid soluble material is taken is mixer and mix well and heated to 78^{O} C	45 min
	At 78^{O} C add water and oil phase and mix with high-speed stirrer	45 Min
3	High shear Homogenization - At 25000 RPM homogenize for 15 Min using Silverson Mixer	15 Min
4	Followed by cooling 10 min and stirring at 5000 rpm at a room temp	45 Min
5	Spray dryer is used to obtain consistency and uniform particle size distribution	15 Min

SLNs are prepared by mixing a lipid excipient with an aqueous emulsifier solution at a temperature above the melting point of the lipid excipient. This creates a hot oil-in-water emulsion, which is then cooled to form solid nanoparticles. Common lipid excipients include fatty acids, fatty alcohols, partial glycerides, triglycerides, and waxes such as carnauba wax or beeswax.

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An emulsifier reduces the interfacial tension between the molten lipid and water, aiding the breakup of the liquid lipid into small droplets under high shear mixing. With the right emulsifier and high shear devices like colloid mills, ultra-Sonicator, or high-pressure homogenizers, the dispersed molten lipid droplets can be reduced to nanometre sizes. Once the desired particle size is achieved, the nano emulsion is cooled to solidify the droplets into SLNs. Emulsifier molecules adhere to the SLN surface and become physically trapped as the wax solidifies.

The nature of the emulsifier molecule determines the surface properties and behaviour of SLNs, both in vitro and in vivo. Selecting the appropriate emulsifier is crucial for formulation and for controlling SLN properties and function.

Anionic emulsifiers such as sodium dodecyl Sulfate produce SLNs with negatively charged surfaces, which attract positively charged molecules. Cationic emulsifiers like Cetyl trimethylammonium bromide create positively charged SLNs, binding negatively charged molecules. Non-ionic emulsifiers such as Tween 20 and Tween 80 result in SLNs with virtually no surface charge and little binding affinity. PEGylated excipients can be included to avoid the reticuloendothelial system and extend in vivo half-life.

When developing uncharged SLNs, it is important to note that many non-ionic emulsifiers become increasingly insoluble in water at higher temperatures, potentially precipitating from the hot aqueous phase at the emulsifier's "cloud point." Non-ionic surfactants must be chosen carefully, considering their cloud point relative to the maximum temperature during manufacturing.

Emulsifiers at the SLN surface help overcome attractive Van der Waals forces that would otherwise cause particle aggregation. Ionic emulsifiers impart surface charge, producing electrostatic repulsion, while non-ionic emulsifiers produce steric repulsion. Both approaches achieve dispersion stability suitable for pharmaceutical shelf life.

SLN formulations for parenteral administration must be sterile. If SLNs are less than 100 nm in diameter, they may be sterilized by filtration through a 0.2-micron filter. Otherwise, terminal heat sterilization may be possible but is rare. Aseptic manufacturing, using sterile excipients and equipment and stringent controls to prevent microbial ingress, is usually required [62-68]

Sovereignty of SLN as active delivery system

Superiority of SLN tropical delivery system for active is as clearly established in Table 4 which clearly express advantages of SLN over other delivery systems is parameters like bioavailability, bio compatibility, oxidation prevention, targeted delivery, versatile administration route and enhanced stability of active [69-73].

Table 4: Active delivery technique clearly indicate superiority of SLN active delivery benefits [69-73]

Active Delivery technique for Formulation Goal			
Formulation Goal	**SLN Encapsulation benefits**	**Particle size reduction**	**Solid dispersion**
Oxidation Prevention of Active	TRUE	FALSE	TRUE
Increase Bioavailability	TRUE	TRUE	TRUE
Target / Controlled delivery	TRUE	TRUE	FALSE
Stability of active	TRUE	FALSE	FALSE

Characterization of SLN

A systematic and appropriate characterisation and analysis of SLN is crucial to demonstrate benefits, performance and quality and stability of product. Several parameters ae discussed below for restored assessment.

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Particle size distribution (PSD)

- ✓ **Electron Microscopy**

PSD can be easily measured by Scanning electron microscopy (SEM) and Transmission electron microscopy (TEM) which can also determine physical characterization of nanoparticles with the former method being used for morphological examination [74]

- ✓ **Sieve Test**

The sieve test is a straightforward method for determining PSD. Samples are weighed and placed on a series of sieves with decreasing mesh sizes, then processed using sieve shakers. The amount remaining on each sieve is calculated to determine particle size distribution [75].

- ✓ **Laser Diffraction Method**

Particle size is analysed by laser diffraction using a particle size analyser (SALD 2101, Shimadzu, Japan), providing the mean diameter based on volume mean diameter (VMD). SLN samples are diluted with double-distilled water prior to measurement, and each sample is measured in triplicate. Zeta potential is analysed with a Malvern zeta analyser (Nano ZS, Malvern, UK) [76].

Zeta Potential

The size characterization and dispersion of SLN is measured by zeta meter to measure zeta potential. The zeta potential's significant value is connected to the stability of colloidal dispersions a higher zeta potential value may lead to particle disaggregation [77].

Active entrapment Ingredient Loading Capacity

The active entrapment and loading capacity percentage is calculated as the percentage of entrapped active ingredient relative to the lipid, using the following formula [78].

Loading Capacity in % = Encapsulated Drug / Total Lipid × 100

Degree of crystallization

The nature and degree of crystallization structure of SLN can be determined by Differential scanning calorimetry (DSC). SLN has tendency to undergo crystallization which disturbs structure, increases particle size and reduces the loading capacity of active and zeta potential decreases which can disturb the long-term stability of product [79].

In Vivo Skin Penetration Study

Male rats obtained from animal facilities are used for skin permeation and drug deposition studies. However, animal testing is now restricted due to ethical and regulatory considerations, and such methods are complex and less accurate [80].

In Vitro Penetration Study

The in vitro release of cosmetic active SLN formulations can be detected using cellulose membrane which is immersed in double-distilled water for 30 minutes before the experiment. About 2 ml of SLN formulations is added to the dialysis bags sealed using standard closures. These bags were then placed in a solution comprising 75 mL of PBS: Tween 80 (19:1; pH 7.4) and sealed with parafilm and aluminum to prevent the evaporation of the receptor phase. The procedure is conducted in a shaking incubator at a constant temperature of 32 °C ± 0.5 °C and a rotating rate of 100 rpm/min. At designated intervals (0, 0.25, 0.5, 1, 2, 3, 4, 5, 6, 8, and 24 h), 0.5 mL aliquots is taken from the receiving phase and replaced with an equal volume of fresh medium to sustain sink conditions. The quantification of release of active is carried out using HPLC method. [81].

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Stability Test

SLN samples and related formulations with actives are stable at 45 °C and 75% relative humidity, compared with those kept at room temperature, in accordance with ICH guidelines for stability testing. The average particle size of nanoparticles tends to increase during storage, possibly due to particle aggregation under varying conditions. However, this effect is not observed in formulations kept at 45 °C and 75% RH [82].

pH Test

It is recommended to keep pH of SLN in between 5.0 to 8.0 to be compatible with SLN tropical application in skin creams, lotion and hydrogel formulations. [83].

Application of SLN

There is various application of SLN listed below depending on expected mode of action [84-92]

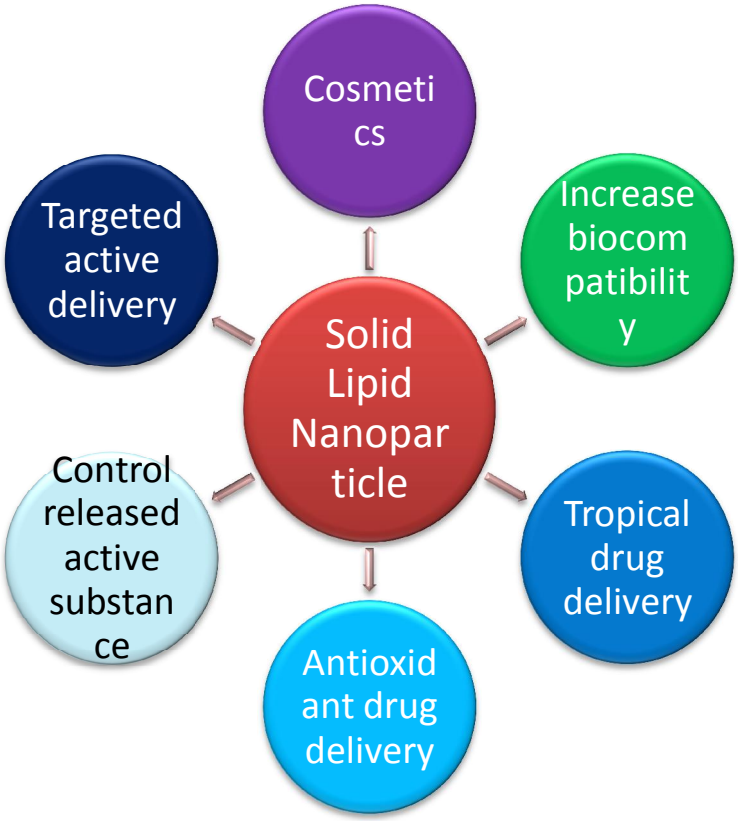

Figure 5 - Application of SLN [84-92]

III. DIFFERENT ROUTES OF ADMINISTRATION OF SLN DELIVERY

Oral administration

SLN are extensively given through oral delivery system for drug and other active ingredients this have been extensively used in pharmaceuticals industries technology, SLN is enhances drug absorption in gastrointestinal track due to its small particle size [93]

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Parenteral administration

The usage of SLN for parenteral pharmaceutical active was found to have higher drug concentrations in lungs, spleen and brain, while the solution led to more distribution into liver and kidneys. SLN showed higher blood levels in comparison to a commercial drug solution after intravenous. [94]

Transdermal administration

Tropical and transdermal application of SLN plays a vital role in a cosmeceutical science. A well known as interesting route of active delivery due to its small particle size molecule which easily penetrate stratum coronium the top layer of skin. This also expand a possibility to penetrate large molecules like peptides, proteins etc which was difficult to absorb in skin however with SLN technology it becomes easy to administer active in skin [95].

Ocular administration

The SLN based delivery system can deliver a visible vehicle delivery for ocular conveyance. The SLN formulations have demonstrated increased capability, drug entrapment and drug delivery to anterior and posterior segment ocular tissues [96]

Pulmonary administration

Solid lipid nanoparticles (SLNs) offer many opportunities as pulmonary carriers due to their physicochemical stability and ability to incorporate both hydrophilic and hydrophobic compounds. These applications include pulmonary infections, lung cancer, and cystic fibrosis, while systemic delivery of biomolecules, like insulin, is also attractive for the treatment of chronic ailments. [97]

Nesal administration

The fact established that the Nesal admiration of drug is more effective compared to oral suspension for kynurenic acid which is useful for brain disorders. Chettupalli et al established fact that improved nasal Noisome gel (SLN technology-based particles) showed enhanced bioavailability that was 2.13 times higher than that of oral medication solutions which is administered in form of nanoparticles [98]

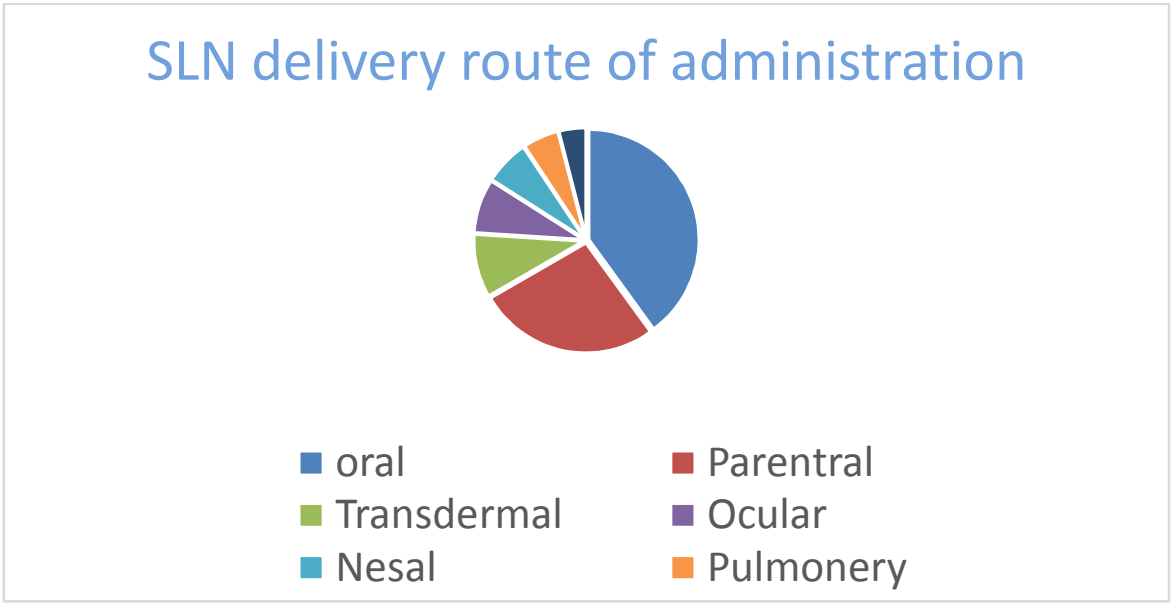

Figure 6 - Different routes of administration of SLN delivery

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IV. CONCLUSION

SLNs offer a versatile platform for encapsulating and delivering cosmetic activities. They have already been commercially applied in topical cosmetics, and their low cost, ease of manufacture, and versatility suggest they will become increasingly common in future cosmeceutical products. SLN production techniques include active incorporation, drug loading, and release capacity, with special focus on drug release methods. As a novel system and targeted drug delivery method, SLN technology can be highly beneficial for the cosmetic industry if deployed scientifically. SLN is relatively novel active delivery system in cosmeceutical industry and have received primary attention since last decade. Therefore, a great future holds a great promise for its precise and targeted therapies which appeal attention and a need for systematic investigation and exploration.

ABBREVIATIONS

Solid Lipid Nanoparticle (SLN), Particle Size Distribution (PSD), Scanning Electron Microscope (SEM)

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