STM JOURNALS

International Journal of
Membranes

Volume 2, Issue 1, 2025
January—June
DOI (Journal): 10.37591/IJM

https://journals.stmjournals.com/ijm

Review IJM

Solid Lipid Nanoparticles in Medicine: Formulation, Characterization, and Future Prospects

Sumaiya Hasim Inamdar[1], Shravni Sunil Kothawale[2], Rutuja Ramachandra Mane[3], Pramod Mahodey Kale[4], Shrivardhan Mahesh Bolaj[5,*]

Abstract

An alternative to conventional colloidal carriers such liposomes, polymeric nanoparticles, and emulsions, solid lipid nanoparticles (SLNs) were created in the early 1990s. Benefits include targeted medicine distribution, controlled drug release, and improved stability. An extensive review of the excipients utilized, the production techniques, including the membrane contractor approach, and the possible advantages and disadvantages of SLNs is given in this work. It investigates secondary stabilization techniques, like freeze-drying and spray-drying, as well as elements of SLN stability and the function of various excipients in preserving stability. There is a detailed analysis of the difficulties in producing SLN and the instrumental methods used. Particular attention is paid to drug incorporation models in SLNs, their release processes, and the analytical techniques employed to assess them. Targeted medication delivery is one of the main uses of SLNs that are highlighted in the research. The different solid lipid-based nanocarrier types – solid lipid nanoparticles, nanostructured lipid carriers, and lipid drug conjugates – as well as their structural variants are investigated. Large-scale synthesis of solid lipid nanoparticles is described using a variety of production methods. To characterizing solid lipid nanoparticles, photon correlation spectroscopy, scanning electron microscopy, and differential scanning calorimetry are suggested as appropriate analytical techniques. The biodistribution and mode of delivery of solid lipid nanoparticles are also discussed. Solid lipid nanoparticles could transform complicated medical conditions.

Keywords: Solid Lipid Nanoparticles, Homogenizer, Hydrophilic, Nanoparticle, Bioavailability

INTRODUCTION

The reduction of materials to micro- and nano-sized particles has been made possible by technological breakthroughs throughout the last 20 years. The surface area of particles grows dramatically when they are reduced to the nanoscale range, which drastically changes their characteristics. Nanoparticles, which are particles with dimensions between 1 and 1000 nm, are used in many different sectors. Particularly in biomedical applications, nanomaterials with high biodegradability and biocompatibility serve as effective carriers in drug delivery systems. To enhance pharmacokinetics (ADME), pharmacodynamics, reduce overall toxicity, manage immune responses, improve bio-recognition, and maximize therapeutic efficacy, researchers have been developing innovative methods. These advancements, known as innovative drug delivery systems (NDDS), integrate multiple fields, such as molecular biology, bio-conjugate chemistry, pharmaceutics, and polymer science. NDDS

***Author for Correspondence**
Shrivardhan Mahesh Bolaj
E-mail: shrivardhanbolai007@gmail.com

[1–3]Student, Department of Pharmacy, Shree Ambabai Talim Sanstha, Tilaknagar, Miraj-Sangli Road, Miraj, Sangli, Maharashtra, India
[4,5]Lecturer, Department of Pharmacy, Shree Ambabai Talim Sanstha, Tilaknagar, Miraj-Sangli Road, Miraj, Sangli, Maharashtra, India

Received Date: October 24, 2024
Accepted Date: March 05, 2025
Published Date: March 10, 2025

Citation: Sumaiya Hasim Inamdar, Shravni Sunil Kothawale, Rutuja Ramachandra Mane, Pramod Mahodey Kale, Shrivardhan Mahesh Bolaj. Solid Lipid Nanoparticles in Medicine: Formulation, Characterization, and Future Prospects. International Journal of Membranes. 2024; 2(1): 1–15p.

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encompasses a wide range of delivery methods, including nanoparticles, erythrocytes, hydrogels, implants, liposomes, microspheres, and transdermal patches. Nanoparticle-based systems have shown great potential in addressing complex biopharmaceutical and pharmacological challenges, making them promise for the treatment of chronic diseases.

The integration of nanotechnology with advancements in functional proteomics, genomics, bioinformatics, and combinatorial chemistry has driven significant progress in drug delivery development [1, 2].

This synergy has expedited the creation of new delivery strategies, crucial for overcoming the limitations of conventional drug delivery systems. The therapeutic efficacy of drugs is strongly influenced by their pharmacokinetics, administration route, solubility, crystallinity, toxicity, and hydrophilic-lipophilic balance (HLB). Effective absorption and delivery require a comprehensive understanding of biopharmaceutics, pharmacokinetics, the route of administration, absorptive surface area, and drug transport mechanisms within the body. Factors, like solubility, crystallinity, and HLB value, also play a pivotal role in developing formulations for active pharmaceutical ingredients (APIs). The HLB scale categorizes drugs into hydrophilic and lipophilic compounds [3, 4]. Lipophilic drugs, in particular, present significant challenges due to low solubility, complicating the development of safe, effective, and cost-efficient delivery systems. Despite these obstacles, tremendous progress has been made in pharmaceutical research. Solid lipid nanoparticles (SLNs) have emerged as a valuable solution for hydrophobic medication formulations. They provide advantages, such as effective drug delivery, low toxicity, and long-term release, making them a versatile alternative to liposome. Nanoparticle-based systems are successful because they can cross tissue boundaries, preserve nanoscale stability, and enable controlled release. However, there are still impediments to their widespread clinical use. Limited availability of safe, regulatory-approved polymers and the high costs of nanoparticle production pose significant challenges. Continued research into safer polymer formulations and cost-effective manufacturing processes will be essential to expanding the clinical utility of nanoparticle-based drug delivery systems. Lipid-based carriers have emerged as a practical solution to the limitations of polymeric nanoparticles, particularly for delivering lipophilic drugs. Solid lipid nanoparticles (SLNs) are especially attractive for improving the efficacy of pharmaceuticals, nutraceuticals, and other bioactive compounds [5, 6].

Their unique properties make SLNs particularly suitable as advanced colloidal drug carriers for intravenous applications. These nanoparticles are formed by dispersing physiological lipids in an aqueous solution containing surfactants. Key advantages of SLNs over polymeric nanoparticles include reduced cytotoxicity and scalability in production. While polyester polymers are commonly used in implants, they often exhibit significant cytotoxicity when internalized by cells. Additionally, producing polymeric nanoparticles at a large scale is typically challenging, expensive, and complex. Since the 1990s, research has increasingly focused on SLNs as a safer, scalable alternative for nanoparticle-based drug delivery. Solid lipid formulations, such as lipid pellets used in oral delivery systems (e.g., Mucosolvan® retard capsules), have long been recognized for their potential [7, 8].

Phospholipids play a crucial role in lipid-based systems like SLNs, offering amphiphilicity, biocompatibility, and multifunctionality. SLNs address the shortcomings of other lipid-based systems, such as liposomes and lipospheres, which often suffer from manufacturing challenges and low drug entrapment efficiency. Typically spherical, SLNs range in size from 50 to 1000 nm in diameter. Essential components of SLN formulations include active pharmaceutical ingredients (APIs), emulsifiers, solid lipids, and an appropriate solvent system [9, 10].

Nanocarrier-based drug delivery systems can be categorized based on their biodegradability and mode of administration, including parenteral, oral, ocular, and topical routes. An ideal nanoparticulate drug delivery system offers high drug loading, low immunogenicity, controlled release, targeted tissue

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distribution, enhanced bioavailability, the ability to carry challenging drugs (such as lipophilic or amphiphilic compounds), and improved patient compliance. SLNs fulfil these criteria by combining the advantages of liposomes, microemulsions, and polymeric nanoparticles. Furthermore, SLNs provide enhanced stability, favorable pharmacokinetics, and efficient integration of therapeutic agents, along with surface modification options, making them highly suitable for intravenous applications.

Figure 1 shows the incorporation of inclusion complexes, such as those with cyclodextrins, can enhance the physicochemical properties, bioavailability, and solubility of solid lipid nanoparticles (SLNs). These complexes contribute to improved drug release profiles in SLNs. Due to the reduced risk of gelling or degradation through lipid modification, SLNs exhibit greater stability compared to other nanoparticle formulations, allowing them to be stored for extended periods, even years. The primary goals of SLNs in drug delivery include enhancing drug bioavailability, managing toxicity, modulating pharmacokinetics and pharmacodynamics, and reducing immunogenicity. These features are particularly valuable in chemotherapy, where conventional drug administration often faces challenges like resistance, poor specificity, and instability. Encapsulating chemotherapeutic drugs in SLNs offers a promising strategy to address these issues [11].

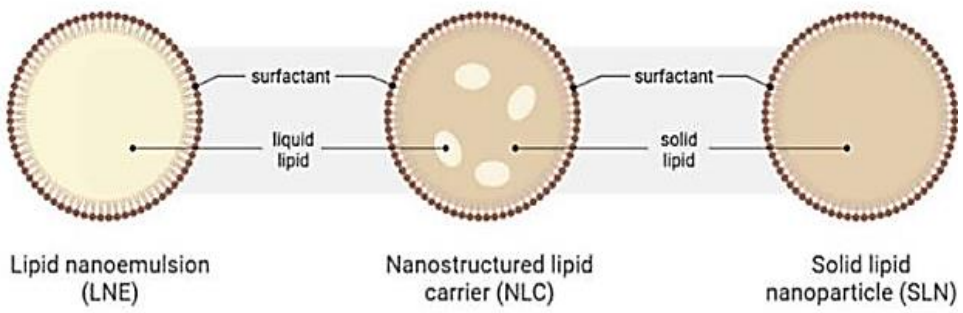

Figure 1. Schematic representation of structure of solid lipid nanoparticles.

The application of SLNs is expanding in fields, such as chemotherapy, treatment of parasitic infections, and tuberculosis therapy. Innovations, like long-circulating SLNs, are driving this growth. Research has demonstrated that SLNs can effectively target malignant cells, yielding promising results in conditions like colorectal cancer and melanoma.

Additionally, SLNs have shown significant potential in the delivery of genetic material. Cationic-modified SLNs can safely transport DNA to specific target sites with low cytotoxicity and high transfection efficiency, making them a powerful tool in gene therapy [12, 13].

Advantages of SLNs

- SLNs are inherently capable of dispersing contract measures to distribute site-specific medications.
- The processes that are employed to make traditional emulsions are important.
- You can use stop-drying to create powdered details.
- Establishing a regulated and gradual release of dynamic medicine is feasible.
- High levels of functional compounds were attained.
- Possible is lyophilisation.
- More control over the release kinetics of the encapsulated chemical.
- The same raw components required for an emulsion are required here.

Disadvantages of SLNs

- Not enough capacity to load medications.
- There is a significant amount of water in the dispersions (70–99.9%).

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- During storage, the likelihood of medication ejection during polymerisation.
- Polymeric transformation may result in the possibility of drug ejection during SLN storage.

BACKGROUND OF STUDY

Solid lipid nanoparticles (SLNs) represent an innovative drug delivery system with significant potential for treating a variety of diseases. The medicine is dissolved or distributed in surfactants, which stabilize SLNs, which are made up of solid lipids, such as fatty acids, triglycerides, and stearic acid. Excellent biocompatibility, strong physiological tolerance, and minimal toxicity are the characteristics that define these nanoparticles. At room temperature and body temperature, they act as solid, stable colloidal carriers. SLNs can encapsulate a wide range of compounds, including as proteins, peptides, thermolabile substances, and medications with suboptimal pharmacokinetic properties. Apart from inhibiting enzymatic breakdown, SLNs enhance drug solubility, stability, and cellular uptake. These properties make SLNs a promising platform for improving the efficacy and distribution of various therapeutic agents [14].

Importance of Study

Solid lipid nanoparticles (SLNs) are a revolutionary medication delivery technology with great promise for improving disease treatment. SLNs, which are made up of solid lipids, such as stearic acid, triglycerides, and fatty acids and stabilized with surfactants, can contain pharmaceuticals in either dissolved or dispersed form. These nanoparticles are renowned for their exceptional physiological compatibility, low toxicity, and low immunogenicity. Additionally, they are stable colloidal carriers that stay solid at both body and room temperatures [15].

SLNs are highly versatile, capable of delivering a wide range of drugs with various physicochemical properties, including proteins, peptides, thermolabile compounds, and drugs with limited pharmacokinetic profiles. They help reduce enzymatic degradation, enhance stability, improve drug solubility, and facilitate cellular uptake. These attributes make SLNs a promising and effective platform for improving the therapeutic efficacy and delivery of a variety of medications [16].

Formulation Techniques

High Shear Homogenization

The high-shear homogenization method, initially used to produce solid lipid nanodispersions, remains widely used due to its simplicity and accessibility. However, this technique can occasionally lead to the formation of microparticles, which may compromise the quality of the dispersion. To prepare solid lipid nanoparticles (SLNs), melt emulsification is employed with high-speed homogenization. Factors, such as emulsification time, stirring rate, and cooling conditions significantly influence the zeta potential and particle size.

For example, lipids, like trimyristin, tripalmitin, and a mixture of mono-, di-, and triglycerides (Witepsol W35, Witepsol H35), were combined with glycerol behenate and poloxamer 188 as steric stabilizers, each at a concentration of 0.5% w/w. The optimal conditions for Witepsol W35 dispersions were achieved at room temperature after 8 minutes of stirring at 20,000 rpm, followed by 10 minutes of cooling and additional stirring at 5,000 rpm. In contrast, the ideal conditions for Dynasan116 dispersions involved emulsification for 10 minutes at 25,000 rpm, with 5 minutes of cooling at 5,000 rpm in a cool water bath (~16°C). While increasing the stirring rate improved the polydispersity index slightly, it did not significantly affect the particle size [17].

Hot Homogenization

Hot homogenization, like emulsion homogenization, occurs at temperatures above lipid melting point. Initially, the drug-loaded lipid melt is blended with the aqueous emulsifier phase at high temperatures to form a pre-emulsion, utilizing high-shear mixing equipment, such as a Silverson-type homogenizer. The quality of this pre-emulsion is critical to the final product, with the best outcomes

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attained with droplet sizes as small as a few micrometres. After the pre-emulsion has formed, high-pressure homogenization is performed at temperatures higher than the lipid's melting point. Higher processing temperatures usually result in smaller particle sizes by decreasing the viscosity of the lipid phase, but they also raise the risk of drug and lipid carrier degradation. For optimal results, the method normally involves repeated passes (Figure 2) [18].

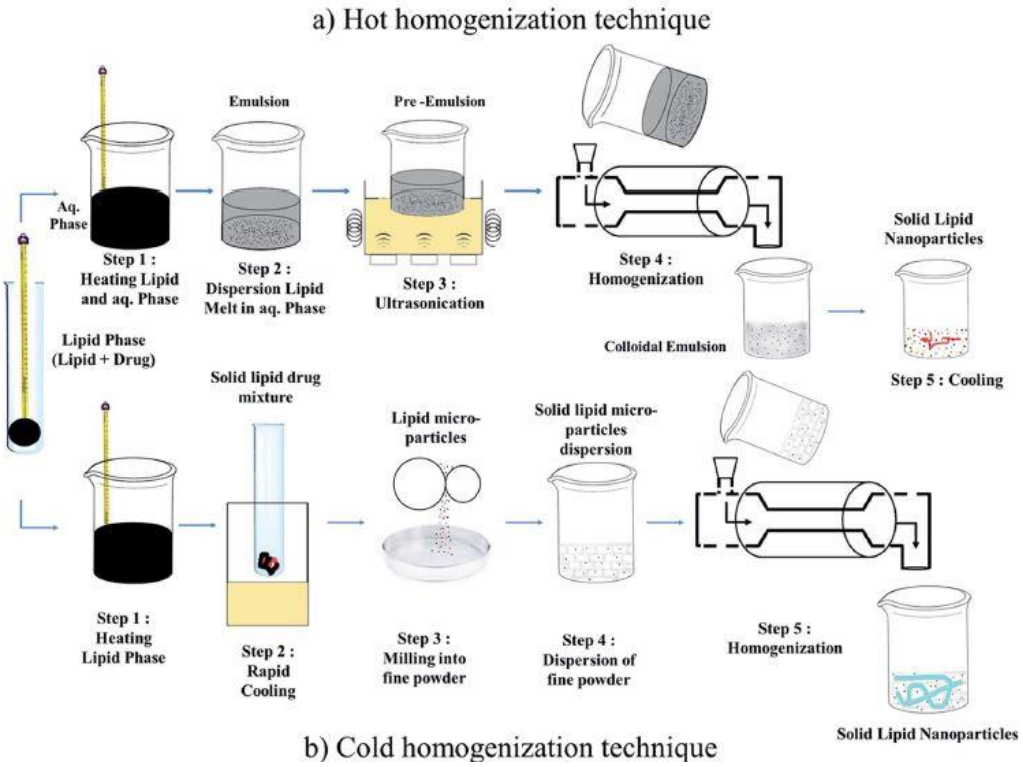

Figure 2. Hot and cold homogenization technique.

Cold Homogenization

Cold homogenization, performed with solid lipids, is a process like milling a suspension under high pressure, where maintaining the solid state of the lipid is crucial through precise temperature control. This method was developed to address the main limitations of hot homogenization, which include:

- Temperature-induced degradation of the drug.
- Drug loss due to partitioning into the aqueous phase.
- Uncontrolled polymorphic changes in the lipid caused by complex crystallization, leading to structural alterations or supercooled melts.

As with hot homogenization, the first step in cold homogenization involves dissolving or dispersing the drug in the melted lipid. The processes then diverge. To prevent the lipid from losing its solid state, the drug-loaded lipid melt is quickly cooled using liquid nitrogen or dry ice, ensuring uniform drug dispersion within the lipid matrix. The solidified lipid is then ground into microparticles, typically ranging from 50 to 100 microns, using ball or mortar milling. The cooling process increases the brittleness of the lipid, facilitating easier milling.

After the microparticles are formed, they are dispersed in a chilled emulsifier solution and homogenized under high pressure at room temperature or lower. Temperature regulation is essential at this stage to compensate for the heat created during processing. Cold homogenization produces bigger particles with a broader size distribution than hot homogenization [19, 20].

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SLN Prepared by Solvent Emulsification/Evaporation

A lipophilic material is first dissolved in a water-immiscible organic solvent, such as cyclohexane, and then emulsified into an aqueous phase to produce colloidal dispersions via precipitation in an oil-in-water (o/w) emulsion. As the solvent evaporates, lipid precipitates in the aqueous solution, resulting in a nanoparticle dispersion. Emulsifiers included lecithin and sodium glycocholate, while cholesterol acetate served as a model drug, resulting in particles with an average diameter of 25 nm. This method was successfully replicated by Siekmann and Westered, who produced lipid acetate microspheres with an average size of 29 nm. (Figure 3) [21].

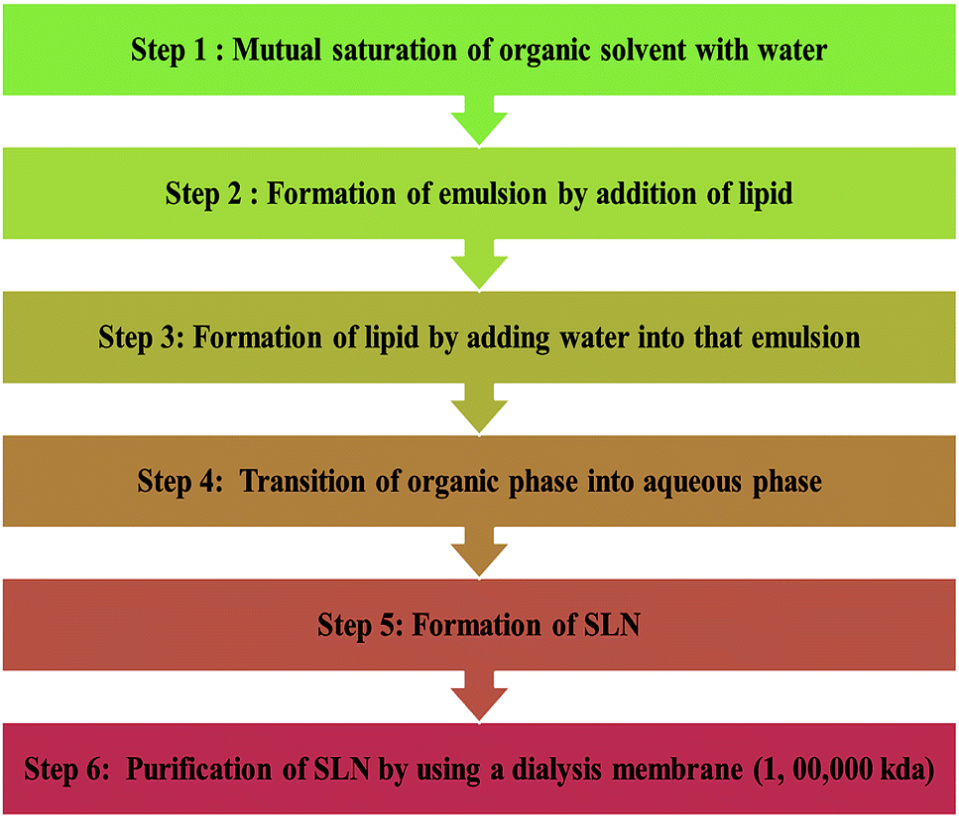

Figure 3. Preparation method of solvent emulsification method.

Micro Emulsion Based SLN Preparations

Solid lipid nanoparticles (SLNs) can also be produced by swirling a clear, optically transparent fluid at temperatures between 65–70°C. An emulsifier (such as polysorbate 20, polysorbate 60, soy phosphatidylcholine, or sodium taurodeoxycholate), co-emulsifiers (such as sodium monooctylphosphate), water, and a low-melting fatty acid (such as stearic acid) are common ingredients. The heated microemulsion is then gently blended into cold water (between 2 and 30°C) while continually swirling. Hot microemulsion to cold water volume ratios typically range from 1:25 to 1:50. The microemulsion's composition is critical to the dilution process. The microemulsion's droplet structure enables the creation of submicron particles without requiring additional energy. Similar techniques have been employed by French researchers, like Fassi, to generate polymer nanoparticles by diluting polymer solutions in water (Figure 4) [22].

The rate of distribution is critical to determining particle size; more lipophilic solvents tend to produce larger polymer particles, while solvents that quickly disperse into the aqueous phase (such as acetone) result in smaller particles. Likewise, the hydrophilic co-solvents in microemulsions likely contribute to the formation of lipid nanoparticles, like how acetone aids in the formation of polymer nanoparticles [23].

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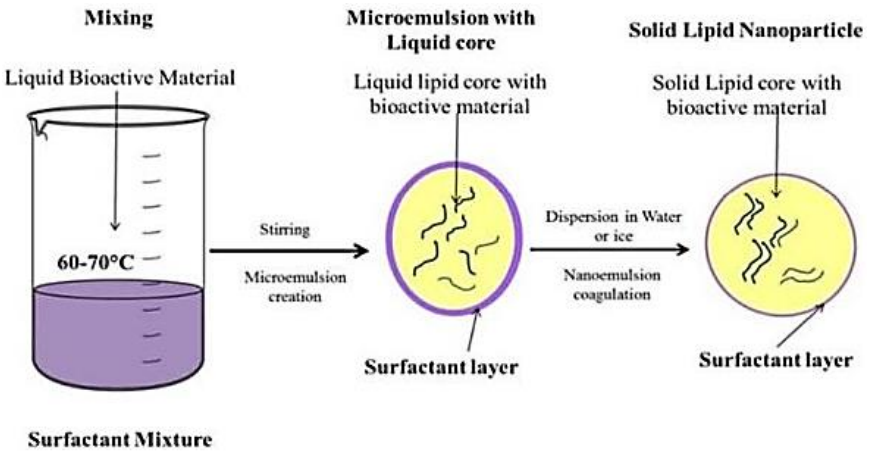

Figure 4. Preparation of SLN by microemulsion technique.

SLN PREPARATION BY USING SUPERCRITICAL FLUID

The main advantage of using this relatively new technique to produce solid lipid nanoparticles (SLNs) is that no solvents are used during processing. Several variations of this platform technology are available for producing both powders and nanoparticles. Supercritical carbon dioxide solution (RESS) rapid expansion is one technique for creating SLNs. For this method, 99.99% pure supercritical carbon dioxide is a great solvent option (Figure 5) [24].

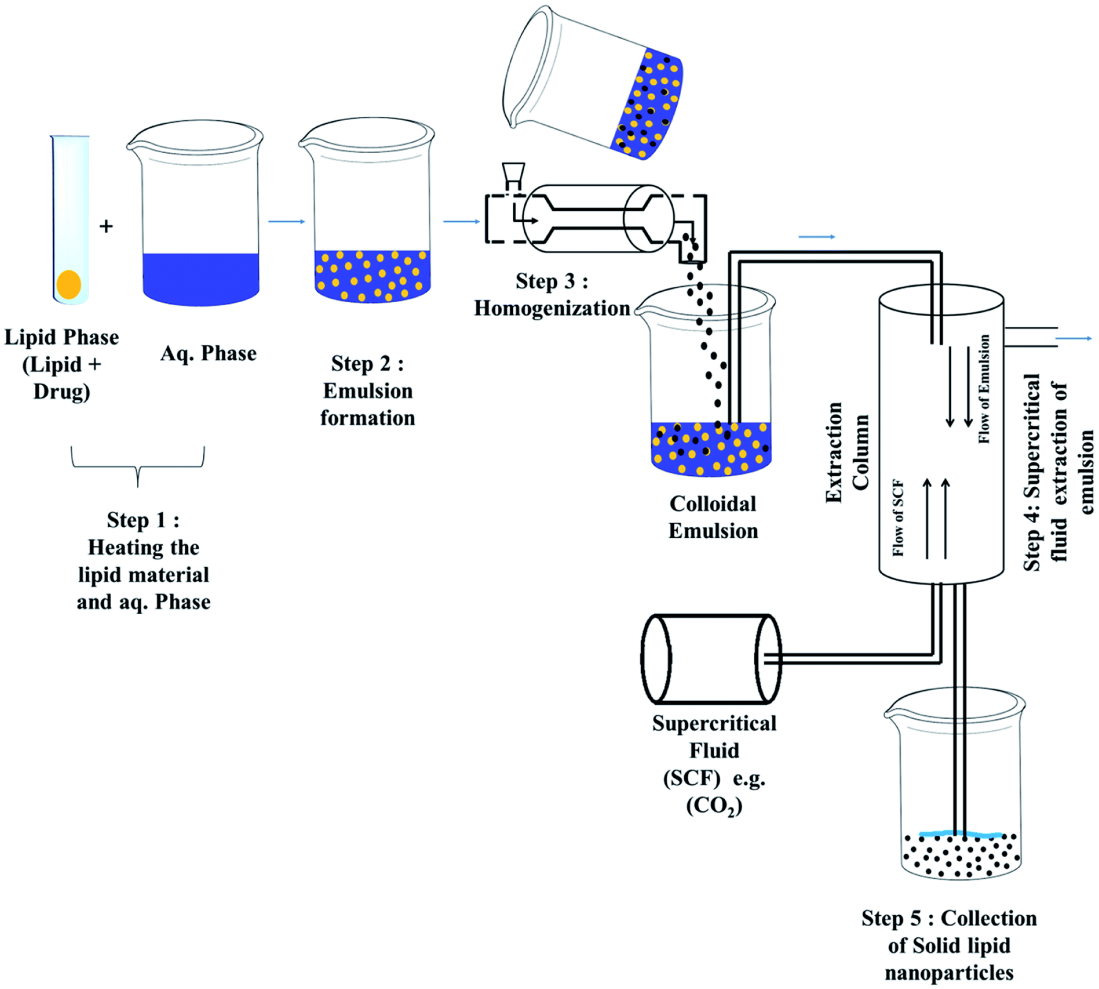

Figure 5. Critical fluid technique for the preparation of solid lipid nanoparticles.

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Spray Drying Method

An aqueous solid lipid nanoparticle (SLN) dispersion can be converted into a medicinal product using this technique, which is less expensive than lyophilization. The process's high temperatures, shear pressures, and partial melting of the particles, however, may cause the particles to aggregate. It is advised to use lipids with a melting point greater than 70°C for spray drying. SLN concentrations of 1% in a trehalose solution in water or 20% in ethanol-water mixes (10:90 v/v) produced the best results [25].

Double Emulsion Method

The advanced solvent emulsification evaporation method is employed to create solid lipid nanoparticles (SLNs) loaded with hydrophilic drugs. In this process, the drug is encapsulated with a stabilizer in a water-in-oil-in-water (w/o/w) double emulsion to prevent the drug from partitioning into the outer aqueous phase during solvent evaporation. Another innovative method for producing SLNs is electrospray. This technique uses electrodynamic atomization to produce spherically shaped, narrowly dispersed SLNs that are less than 1 mm in size. A significant advantage of this approach is its ability to directly produce SLNs in powder form [26].

Ultra Sonication or High-Speed Homogenization

Additionally, solid lipid nanoparticles (SLNs) can be produced by high-speed stirring or sonication, both of which need common laboratory apparatus. The drawbacks of this method include the possibility of a broader particle size distribution that can extend to the micrometer range, which over time may result in particle growth and physical instability. Furthermore, there is a chance that the ultrasonication process will contaminate the metal. High-speed stirring and ultrasonication have been investigated by several research groups to overcome these problems and produce a stable formulation, especially when done at high temperatures (Figure 6) [27].

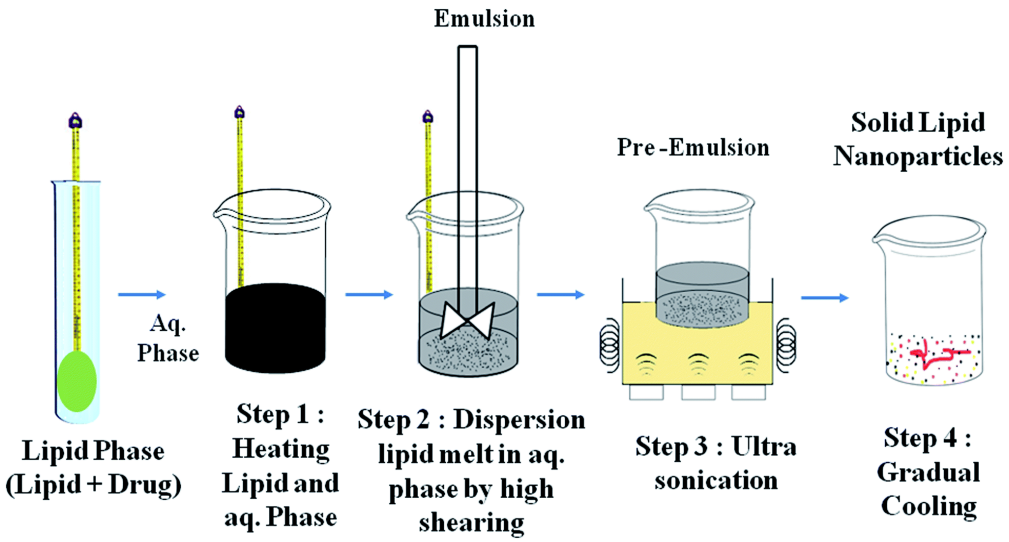

Figure 6. Preparation of SLN by ultrasonication method.

PREPARATION OF SEMISOLID SOLID LIPID NANOPARTICLES

Another approach to creating solid lipid nanoparticles (SLNs) is sonication or high-speed stirring, which utilizes commonly available laboratory equipment. However, this method has some drawbacks, including a broader particle size distribution that may extend into the micrometer range, potentially leading to physical instability and particle growth during storage. There is also a risk of metal contamination during the ultrasonication process. To address these challenges and enhance formulation stability, several research teams have explored combining high-speed stirring with ultrasonication, especially at elevated temperatures [28].

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Electrospray Technique

Using electrodynamics atomization, a new and creative method for creating solid lipid nanoparticles (SLNs), narrowly dispersed spherical SLNs smaller than 1 mm are produced. SLNs can be directly produced in powder form using this approach [29].

Oil/Water (o/w) Microemulsion Breaking Technique

To generate a microemulsion, the medication, surfactant, and co-surfactant are first combined with the lipid melt and heated to the same temperature as the lipids melting point. The final step is to disperse the resulting microemulsion in water at temperatures ranging from 2 to 100°C (Figure 7) [30].

Figure 7. Preparation of SLN by oil/water (o/w) microemulsion breaking method.

Solvent Injection Method

This procedure involves dissolving lipids in a solvent that dissolves in water, after which they are inserted by a needle into a swirling aqueous solution that might or might not contain surfactants. The kind of injection solvent used lipid content, the volume of injected lipid solution, and the viscosity and diffusion characteristics of the lipid solvent phase into the aqueous phase are all significant variables influencing the generation of nanoparticles with this technique (Figure 8) [31].

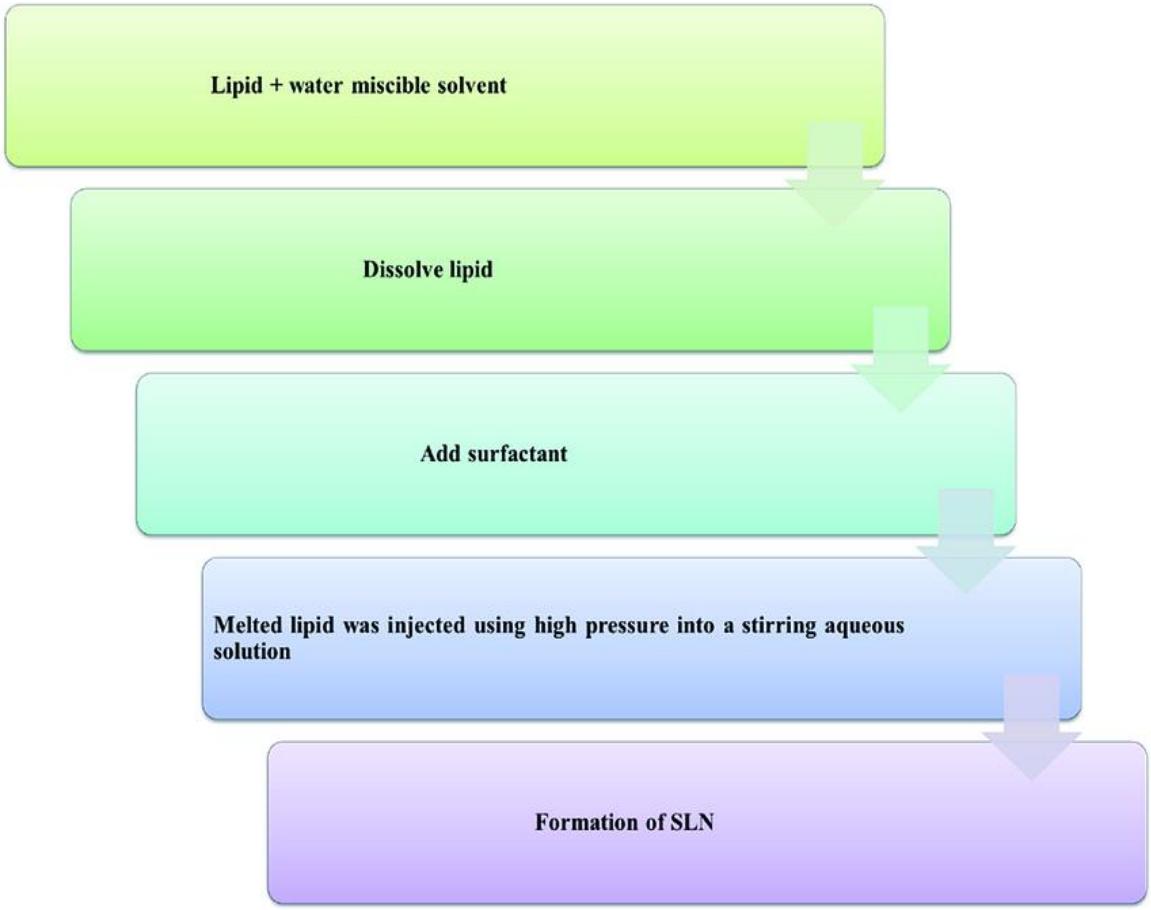

Figure 8. Preparation of SLN by solvent injection method.

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Film Ultrasound Dispersion

Following the decompression, turning, and dissipation of the natural arrangements made of lipid and medication, a lipid film is framed, in which a watery arrangement holds the emulsions. Ultrasound is used as the last test to diffuse the SLN with the tiny and homogenous molecular measurement (Figure 9) [31].

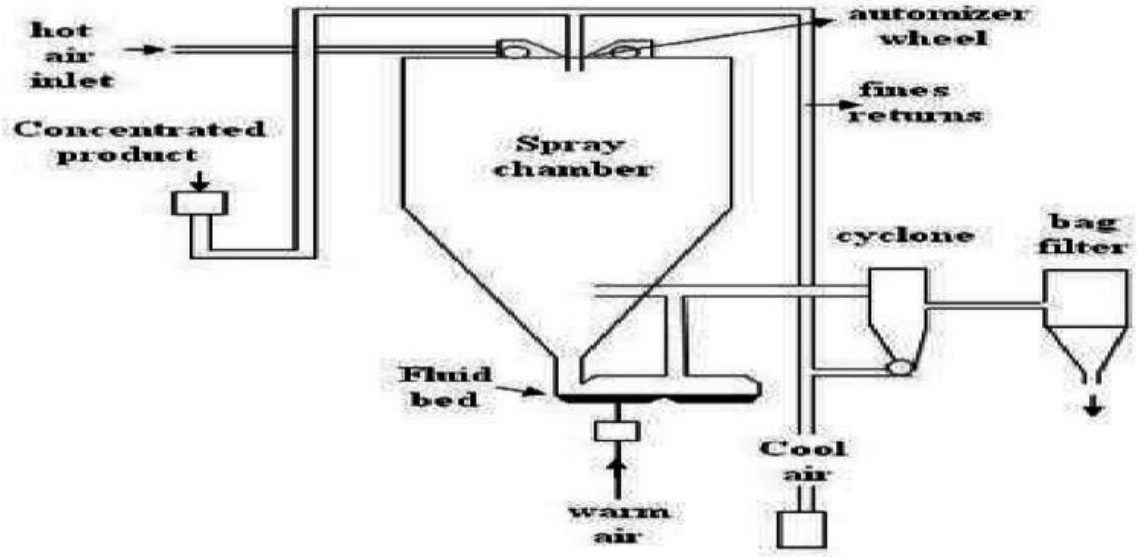

Figure 9. Preparation of SLN by Film ultrasound dispersion.

CHARACTERIZATION OF SOLID AND LIPID NANOPARTICLES

Determination of Incorporated Drugs

The amount of drug incorporated into solid lipid nanoparticles (SLNs) is evaluated by removing the free drug and solid lipids from the liquid media. Ultracentrifugation, centrifugation, filtration, and gel permeation chromatography are commonly used methods for achieving this separation. Alternatively, the drug content can be directly assessed by extracting the drug with an appropriate solvent under ideal conditions and analysing the resultant solution.

Various models have been proposed to describe the localization of drug molecules within SLNs:

- *Improved Shell Model:* In this model, the drug is positioned at the interface, either due to rapid solidification of the lipid matrix or the drug's strong affinity for the interface. Drugs localized in this manner often exhibit an initial burst release during drug delivery [32].
- *Homogeneous Matrix Model:* This model describes a uniform distribution of the drug throughout the lipid matrix, resembling a solid solution.
- *Advanced Core Model:* Here, the drug is concentrated at the core of the SLNs, possibly due to the drug solidifying faster than the lipid matrix. This configuration is advantageous for achieving a controlled, film-based release pattern.

While the chemical stability and release kinetics of drugs are closely related to their localization within SLNs, further research is required to validate these models and optimize their applications in drug delivery systems [33].

IN-VITRO DRUG RELEASE STUDIES

In-vitro drug release studies are valuable for both quality control and predicting in vivo kinetics. Drug release profiles can be assessed using dialysis tubing or a tubing-free method. In the dialysis tubing method, the SLN dispersion is placed into prewashed dialysis tubing, which is then securely sealed and

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dialyzed against a dissolution medium at a constant temperature with continuous stirring. Samples are collected at various time intervals, centrifuged, and analysed for drug content. A novel approach, reported by Impose and Benita, avoids enclosing the colloidal drug carrier in a dialysis sac and utilizes reverse dialysis. However, this method lacks the sensitivity needed to characterize the rapid drug release rates often observed in colloidal carriers [34].

Storage Stability

Monitoring alterations in particle size, drug content, appearance, and viscosity over time allows one to evaluate the physical stability of solid lipid nanoparticles (SLNs). Another option for this is thin-layer chromatography. Long-term stability is greatly influenced by external variables like temperature and light [35].

For a dispersion to remain physically stable, the zeta potential should generally remain above 60 mV. Storage conditions significantly influence stability:

- *4°C:* The most favourable storage temperature, ensuring optimal stability.
- *20°C:* Long-term storage at this temperature does not result in aggregation of drug-loaded SLNs or significant drug loss.
- *50°C:* Particle size increases quickly, which suggests decreased stability. The integrity and functioning of SLNs must be preserved throughout time under ideal storage conditions.

Crystallization Tendency and Polymorphic Behavior of SLNs

The crystallization of lipids requires particular attention since it has a major effect on medication incorporation and release rates. The particles' solid state is important because it limits the mobility of the pharmaceuticals that are encapsulated, preventing drug leakage from the carrier. X-ray diffraction and thermal analysis are crucial techniques for determining the physicochemical state of particles. The two thermal analysis methods that are most employed to provide insight into the thermal behaviour and stability of SLNs are differential thermal analysis (DTA) and differential scanning calorimetry (DSC) [36, 37].

Electron Microscopy of Solid Lipid Nanoparticles

Solid lipid nanoparticles (SLNs) were observed using transmission electron microscopy (TEM). SLN samples were diluted tenfold and then mounted on a gold plate. The mounted plates were allowed to dry and examined under the TEM without the use of any staining agents. A CCD camera and a digital imaging system integrated with the TEM were employed to visualize the SLN [38].

Zeta Potential of Solid Lipid Nanoparticles

With a Zetasizer, the zeta potential of solid lipid nanoparticles (SLNs) was ascertained. Deionized water was used to dilute the samples adequately, resulting in viscosities ranging from 50 to 200 Kcps for precise measurements. The zeta potential was then measured directly after the samples were put into the cuvette of the device (Figure 10) [39, 40].

FUTURE OPPORTUNITIES AND CHALLENGES

Nanoparticles and nanoformulations have already demonstrated significant success as drug delivery systems, and their potential for a wide range of applications continues to grow. These include anti-tumours therapy, gene therapy, AIDS treatment, radiotherapy, protein and antibiotic delivery, virostatic therapies, vaccines, and as carriers to bypass the blood-brain barrier. Nanoparticles offer substantial advantages in terms of drug targeting, delivery, and release, and their ability to combine diagnosis with therapy makes them a cornerstone of nanomedicine. The key objectives are to enhance their stability in biological environments, improve the bio-distribution of active compounds, increase drug loading capacity, target specific sites, and ensure efficient transport, release, and interaction with biological barriers. However, the cytotoxicity of nanoparticles or their degradation products remains a significant

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concern, and improving their biocompatibility is a crucial area of ongoing research. Several technological challenges must be addressed, including the development of:

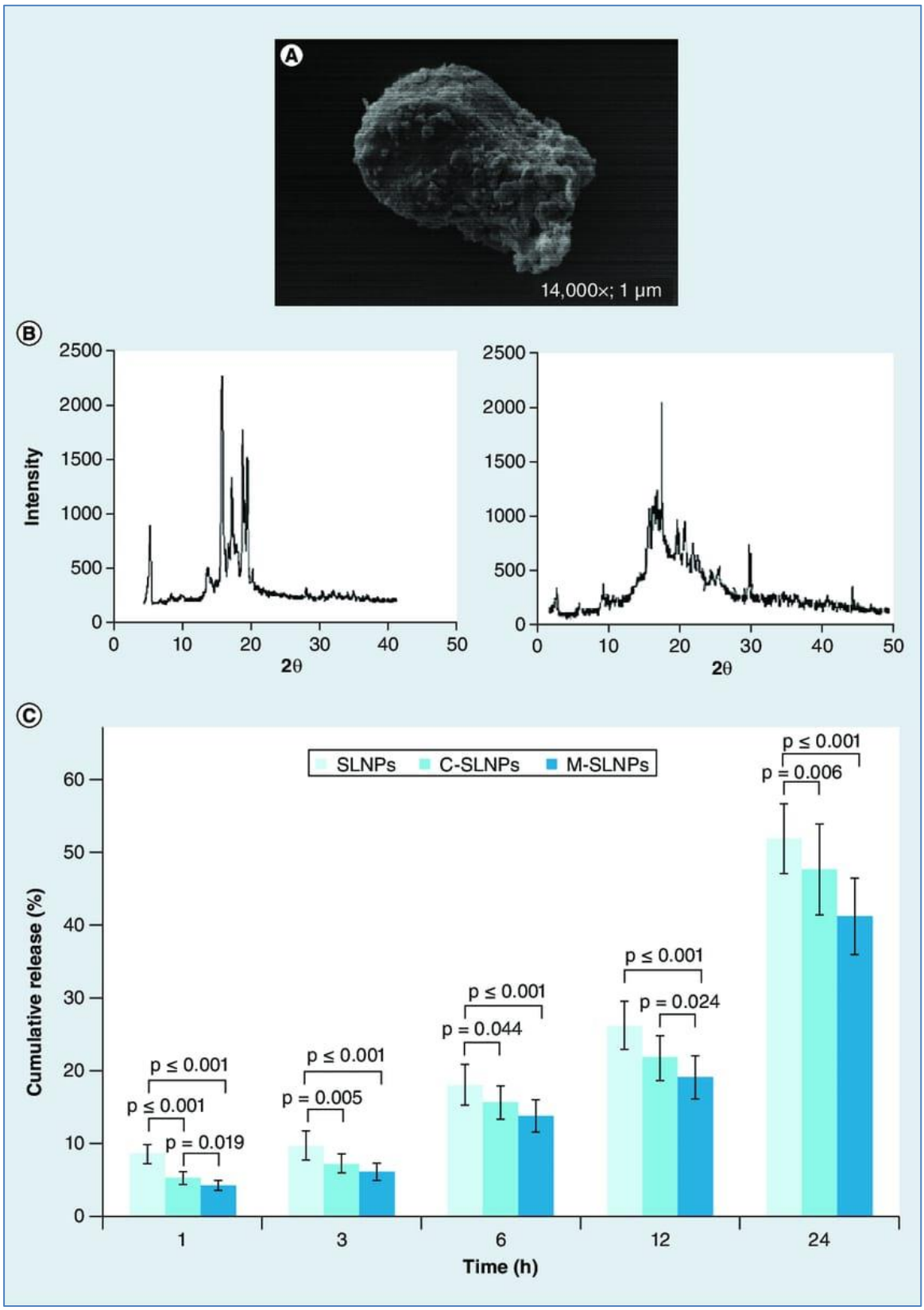

Figure 10. Schematic diagram of particle size and zeta potential.

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CONCLUSIONS

Nanoparticles offer a promising solution for controlled and targeted drug delivery. The rise of nanotechnology is set to revolutionize the drug delivery sector, impacting nearly every mode of administration, from oral to injectable. The benefits for both doctors and patients could include reduced drug toxicity, lower treatment costs, improved bioavailability, and the prolonged economic viability of proprietary drugs. This would lead to earlier, more personalized diagnoses and treatments, enhancing the effectiveness of medications while minimizing side effects. Moreover, nanoparticles hold great promise as a platform technology for creating molecular-specific contrast agents. Nanoparticulate systems are particularly effective in transforming poorly soluble, poorly absorbed, and unstable bioactive substances into viable, deliverable drugs. since of their small size and mobility, nanoparticles can reach a variety of biological objectives since they typically have better intracellular absorption than microparticles. Early in the 20th century, Paul Ehrlich proposed the idea of the "magic bullet" – a medication that could get to the appropriate place in the body at the right time and concentration without producing adverse effects on the way there or back. A partial realization of this idea may be possible with solid lipid nanoparticles (SLNs). Furthermore, the shared objective of regulated medication delivery is successfully accomplished by SLNs.

As a relatively young drug delivery system, SLNs have attracted attention since the early 1990s, and their future is promising, with many patented SLN-based dosage forms expected to emerge.

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