

Review

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Review

Personalized Medicine and Nanotechnology: Transforming Modern Therapeutics

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Abstract: The new trend in the shape of nanotechnology is, however, very lately revolutionizing modern drug delivery to the target sites by very sophisticated nanocarriers. Nano scale vehicles confer solubility and, accordingly, the possible level of bioavailability may relate to the promised assurance of the targeted therapy. Nanocarrier-based present delivery mechanisms form some of it in the mode of liposomes, nanoparticles, proniosomes, etc. Among them, PEGylation and receptor-mediated targeting by liposome technology improve its efficiency and circulation time in the blood. Liposomal inhalation therapy, chewable tablets, and mouth-dissolving films will further increase the patient-friendly route of administration. Proniosomes are stable and scalable alternatives to liposomes with enhanced drug retention. Hybrid nanocarrier systems-once combining vesicular and non-vesicular approaches-further refine controlled release and multifunctional therapeutic strategies. Liposomal antibiotics provide answers to the problems of antibiotic resistance; nanocarrier-based herbal drug formulations would improve bioavailability. Clinical translation, however remains a tough challenge ahead to progress in these areas for improvement in biocompatibility, scalability, and regulatory compliance, so the above trends would focus the future more on AI-driven nanomedicine, stimuli-responsive carriers, gene-editing nanotechnology, even biomimetic drug transport systems for precision targeted and patient-specific therapeutics. This review should describe the present landscape of development and challenges within the convergence of nanotechnology with personalized medicine for transformative applications.

Keywords: nanocarriers; personalized medicine; liposomal drug delivery; precision therapeutics; hybrid nanotechnology

1. Introduction to Personalized Medicine and Nanotechnology

1.1. Evolution of Drug Delivery Strategies

The systems today for drug delivery have developed nanotechnology-based systems that surmount the traditional fears of low bioavailability and systemic toxicity. The oldest formulations of drugs were inaccurate; hence, it led to side effects related to improper delivery of drugs. Drug delivery has advanced with nanocarriers like liposomes and polymeric nanoparticles since it enables the release in a controlled manner toward a site in the body [1].

Such advancements, for example, in the optimization of drug therapy meant the integration of nanotechnology with personalized medicine-both its formulation was to be designed according to genetic and molecular profiles. Enhanced therapeutic yields could, thus lead to diseases such as cancers and neurodegenerative disorders because their targeted drug delivery would minimize such chances of inducing toxicity along with declining efficacy at hand [1].

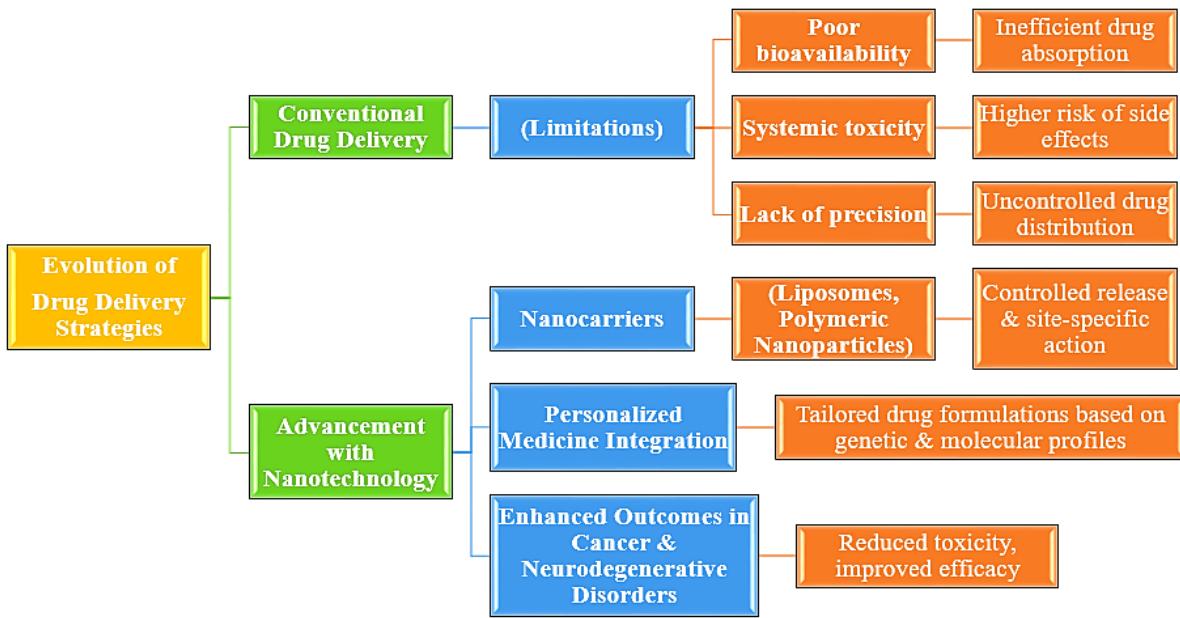


Figure 1. Evolution of Drug Delivery Strategies^[1].

1.2. Targeting Methods and Their Role in Modern Therapeutics

This results in reduced systemic side effects due to targeted delivery of drugs. Targeted drug delivery can be further sub-divided into two categories. First, one is the EPR effect based on the passive targeting, and the other is the active targeting wherein ligands, such as antibodies or peptides, are used for the transport of drugs to targeted cells [1].

Recent developments in this area are pH-, temperature-, or enzyme-cleavable carriers that deliver drugs according to changes in these variables. This gives the field relevance in precision medicine, which includes personalized treatment focused on improving outcomes but lessening side effects [1].

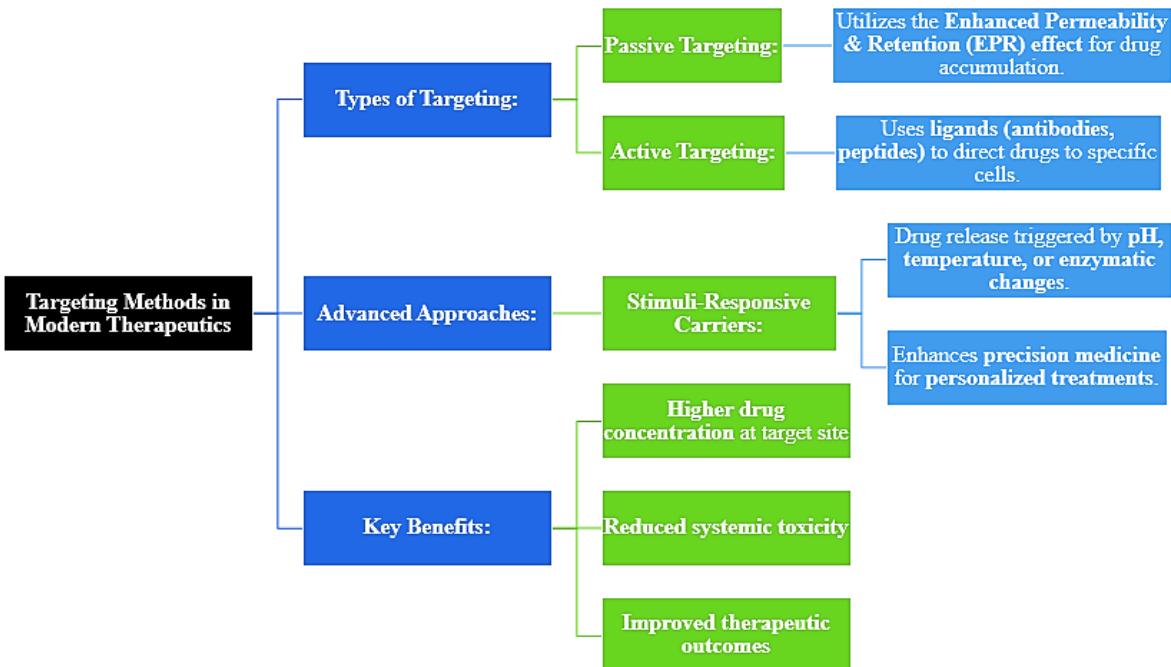


Figure 2. Targeting Methods in Modern Therapeutics.

2. Nanocarriers

2.1. Liposomal Vesicular Delivery Systems: Innovations and Mechanisms

Liposomal drug delivery systems revolutionized modern therapeutics with the control of a controlled, site-specific drug release. The enhanced stability of the drugs, lengthening their time in circulation and lowering their toxicities, came through the carriers formed by the vesicular system, which had lipid bilayers. The more recent developments that improved bioavailability and efficacy for treatment are stealth liposomes and ligand-targeted vesicles [2].

2.2. Nanoparticles in Advanced Drug Delivery

In precision medicine with nanoparticles, drug targeting and controlled release are achieved. The small dimensions can also ensure deep penetration of tissues for treatments of cancers and neurological diseases. Functionalized by polymers or antibodies, increased specificity is achievable in the targeting of drug delivery, ensuring desirable therapeutic benefits without significant adverse effects [3].

3. Liposomal Drug Delivery in Personalized Therapeutics

3.1. Core Principles and Structural Components

Liposomal drug delivery systems exploit the phospholipid bilayers to encapsulate both hydrophilic and lipophilic drugs. They are biocompatible, have controlled release mechanisms, and can evade biological barriers; thus, they are perfect for targeted therapies. Their therapeutic efficiency is further improved through structural modification, including charge manipulation and surface functionalization [3].

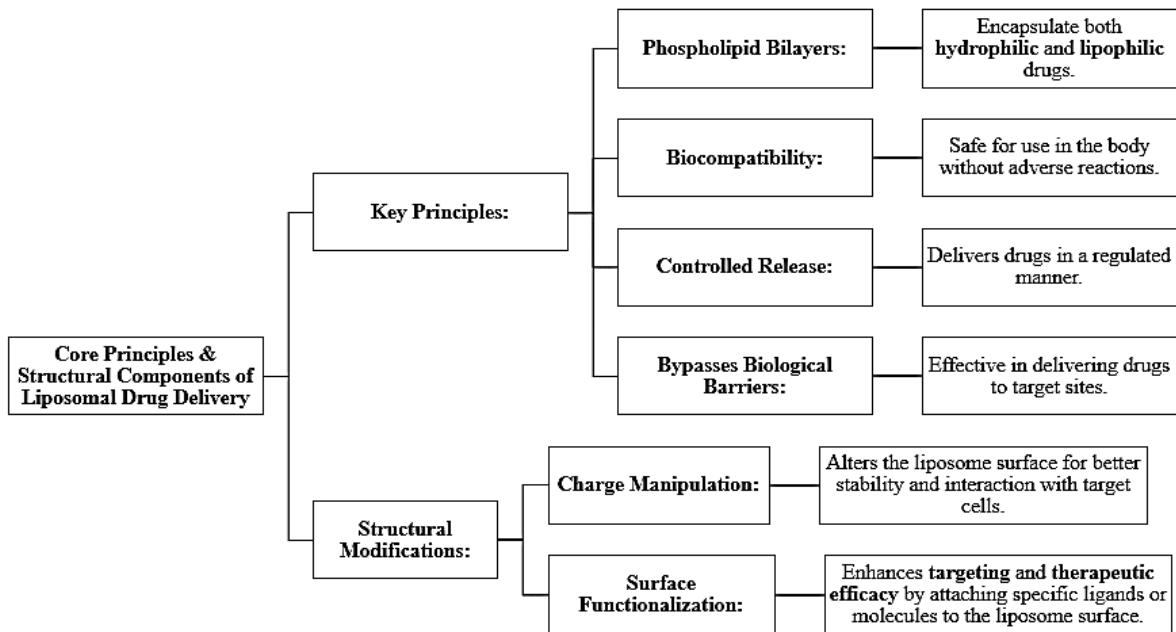


Figure 3. Core Principles and Structural Components Liposomal drug delivery systems.

3.2. Drug Encapsulation and Release Dynamics

The encapsulation efficiency and controlled release of drugs are some parameters through which the efficacy of carriers can be determined. Lipid composition, pH sensitivity, external triggers involving temperature, and enzymatic activation control the kinetics of release. Recently, site-specific

drug delivery, mainly in cancer therapy, has attracted more attention to the amounts of recipients using pHresponsive and enzyme-activated liposomes [3].

3.3. New Developments in PEGylated Liposomes for Long Circulation Periods

Pegylation, which is the coupling of polyethylene glycol to liposomes, decreases immune recognition, and it increases systemic circulation. The half-life is much longer for the stealth liposomes, the biodistribution is more favorable, and the clearance rate is reduced significantly, which places them uniquely advantageous in chronic diseases and chemotherapy [4].

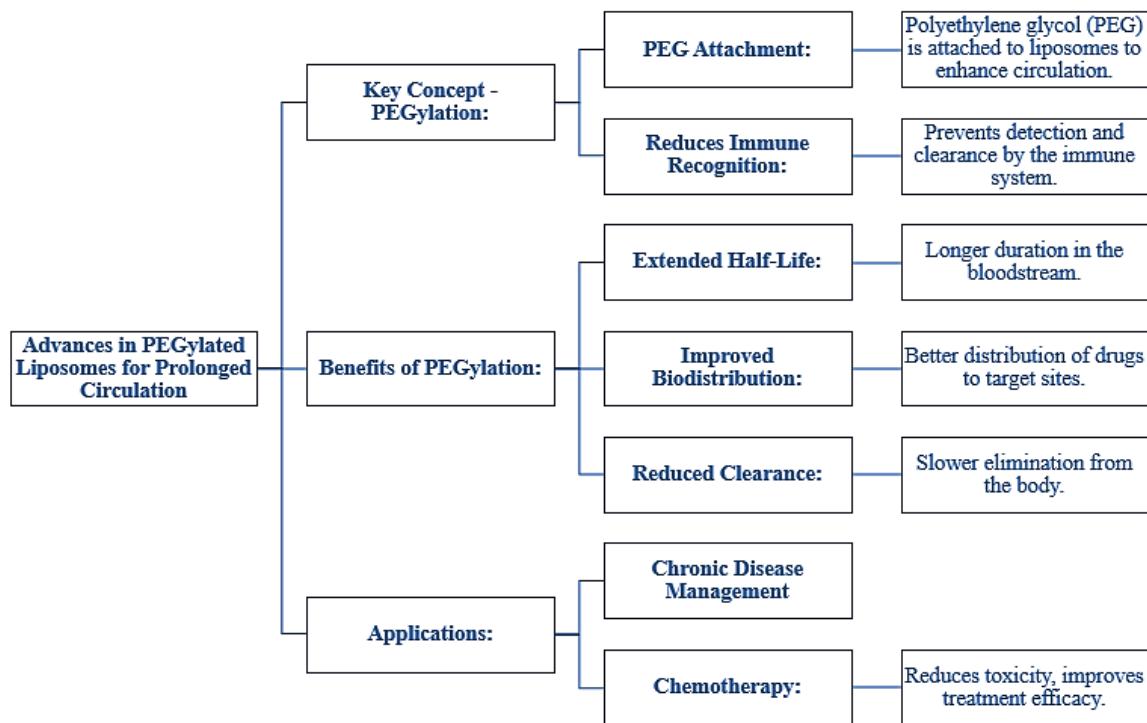


Figure 4. Advances in PEGylated Liposomes for Prolonged Circulation.

4. Naso-Pulmonary and Oral Drug Delivery

4.1. Liposomal Inhalation Therapy for Pulmonary Diseases

Liposomal inhalation therapy offers a non-invasive, targeted delivery of the condition, including asthma, tuberculosis, and pulmonary fibrosis. Inhalable liposomes are an innovative alternative for chronic lung diseases since they have the potential to improve drug retention in the lungs while minimizing systemic side effects [4].

4.2. New Technologies in Chewable and Effervescent Tablet Technologies

These products are chewable and effervescent, so they improve the compliance of pediatric and geriatric patients. An effervescent formulation increases drug solubility and absorption in the body; a chewable tablet is simply an alternative route to the classic oral intake of solid dosages. Such innovative formulations result in better therapeutic response for conditions in which immediate onset of therapeutic action is required [5], [7].

4.3. Mouth-Dissolving Films for Enhanced Bioavailability

Mouth-dissolving films, known as MDFs, is fast-disintegrated drug delivery technology that circumvents the issue of first-pass metabolism and thus increases the bioavailability of drugs. It would be highly useful for patients who have dysphagia and a drug to be absorbed as quickly as possible—for example, cardiovascular or analgesic drugs [6].

Table 1. Naso-Pulmonary and Oral Drug Delivery Technologies.

No.	Drug Delivery Method	Mechanism	Advantages	Applications
1	Liposomal Inhalation Therapy	Liposomes encapsulate drugs for direct pulmonary delivery	Targeted drug delivery, prolonged retention, reduced systemic side effects	Asthma, tuberculosis, pulmonary fibrosis [4]
2	Chewable & Effervescent Tablets	Chewable tablets provide an alternative solid dosage form; effervescent tablets enhance drug solubility	Improved compliance, rapid drug absorption, better taste	Pediatric & geriatric patients, immediate-action drugs [5], [7]
3	Mouth-Dissolving Films (MDFs)	Rapid disintegration in the mouth, bypassing first-pass metabolism	Increased bioavailability, faster onset, useful for dysphagic patients	Cardiovascular drugs, analgesics, emergency medications [6]

Nomenclature

- **Liposomal Inhalation Therapy:** Liposome-based drug formulations designed for pulmonary administration to enhance retention and reduce systemic exposure [4].
- **Effervescent Tablets:** Solid dosage forms that dissolve in liquid, enhancing drug solubility and absorption [5], [7].
- **Chewable Tablets:** Solid oral dosage forms that disintegrate upon chewing for easier ingestion [5].
- **Mouth-Dissolving Films (MDFs):** Thin polymeric films that rapidly dissolve in the mouth for fast drug absorption [6].

5. Proniosomes: A Competitive Alternative to Liposomes

5.1. Fundamentals and Core Composition of Proniosomes

Proniosomes are water-soluble dry carriers, which become niosomes when they contact water. Primarily, these consist of nonionic surfactants, stabilizers, and cholesterol. Proniosomes have more stability in the drugs, easier storage, and controlled release. This self-assembly mechanism is quite effective in drug delivery, especially in both hydrophilic and hydrophobic drugs, and leads to increased bioavailability [8].

Table 2. Fundamentals and Core Composition of Proniosomes.

No.	Aspect	Details	Advantages	Applications
1	Core Composition	Made of nonionic surfactants, stabilizers, and cholesterol	Better stability and bioavailability	Suitable for both hydrophilic & hydrophobic drugs [8]
2	Mechanism	Self-assembly into niosomes upon hydration	Simplifies drug encapsulation and improves drug release control	Targeted and controlled drug delivery [8]
3	Stability & Storage	Exists in a dry state; highly stable at room temperature	Easier storage, longer shelf-life	Useful in formulations requiring extended storage [8]

5.2. Comparison with Liposomes

Although both proniosomes and liposomes present promises in terms of biocompatibility and targeted delivery, proniosomes are known for a far longer shelf life and better stability, and hence economical compared to those of liposomes. Proniosomes also foreclose the necessities of specific storing conditions, issues associated with the oxidation and decomposition of lipids in liposomes [8], [9].

Table 3. Comparative Analysis – Proniosomes vs. Liposomes.

No.	Aspect	Proniosomes	Liposomes	Advantages of Proniosomes
1	Stability	More stable due to dry form	Prone to oxidation and hydrolysis	Longer shelf-life, minimal degradation [8], [9]
2	Storage	Room temperature storage	Requires refrigeration, sensitive to temperature	No need for special storage conditions [8]
3	Cost	Cost-effective and scalable	Higher production costs	More economical alternative [9]

6. Targeted Drug Delivery for Precision Medicine

6.1. Surface-Modified Nanocarriers for Disease-Specific Targeting

Recent advances in the technology of surface modification, especially for attachment and conjugation to antibodies, suggest that nanocarriers will be engineered to specifically recognize diseased tissues. It significantly reduces unwanted secondary effects in the body and enhances the therapeutic action with targeted modifications targeting cancerous cells or inflamed tissues or localized to a cellular organelle [9].

6.2. Active Targeting Strategies in Liposomal Drug Delivery

Active targeting includes receptor-mediated endocytosis, pH-sensitive drug release, and biomarker-guided delivery. Examples are targeted liposomes toward folate-based cancer therapy, HER2-directed liposomes, and breast cancer treatment, which proved the concept that site-specific action of drugs while enhancing cellular uptake and reducing the systemic toxicity are possible [10].

7. Liposomal Antibiotics and Herbal Drug Delivery

7.1. Addressing Antibiotic Resistance through Liposomal Nanocarriers

Liposomal formulation is used to strengthen the effect of antibiotics: Increased penetration drug; protection to degradation; weakening the resistance in the bacteria. In addition, another liposome-based formulation containing the amikacin, vancomycin, and ciprofloxacin entrapped within, has also had higher bioavailability and gradual drug release, thereby becoming the primary condition for managing infection caused through multidrugresistant mechanisms [11], [12].

7.2. Role of Liposomes and Proniosomes in Herbal Drug Delivery

These liposomal and proniosomal formulations have witnessed an intensive improvement in solubility and bioavailability of the plant drugs along with targeted delivery. The encapsulation of herbal extracts, curcumin, quercetin, and *Tribulus terrestris*, in vesicular systems showed highly remarkable improvement of their therapeutic activity when applied on chronic diseases of inflammation and metabolic disorders [13], [14].

8. Future Perspectives in Personalized Medicine and Nanotechnology

8.1. Hybrid Nanocarrier Systems: Vesicular and Non-Vesicular Platforms

The future of nanomedicine hybrid drug delivery systems includes vesicular and non-vesicular platforms, such as liposomes and proniosomes on one hand, and polymeric nanoparticles, dendrimers, and micelles on the other. This will enhance stability, control release, and multifunctional targeting. Lipid-polymer hybrid nanoparticles have demonstrated good potential in oncology and neurodegenerative therapies by promoting synergistic action of drugs and prolonged circulation [15].

8.2. Clinical Translation and Future Integration of Nanomedicine

Although there have been tremendous advances, clinical translation remains an issue because of scalability and regulatory concerns, such as long-term evaluation of safety. Both FDA and EMA emphasize biocompatibility, reproducibility, and toxicity assessment in translating nanocarriers to the clinical field. New technologies involving 3D bioprinting, AI-driven formulation design, and patient-specific nano drug development will put within the realm a possibility of translating scientific research into realities and develop a platform that is to be tapped to bridge to accelerate the full integration of the personalized nanomedicine into a mainstream health system [16].

8.3. New trends in nanotechnology drug delivery

Developments in nanomedicine in future will involve further development of responsive carriers that react to pH/temperature stimuli; enzymatic sensibility and using exosome based drug delivery with gene editing CRISPR-filled nanoparticles. Research is also witnessing the advancement with self-assembling nanostructures coupled with bio-inspiring nanocarriers; virus mimicked nanoparticles, the most efficient would be those bearing cell membrane- coated vesicles for most successful and biomimetic drug translocation. Nanorobotics in its evolving phase, AI-driven nanoformulations, and the *in vivo* tracking of nanocarriers in real time will revolutionize the field of precision medicine, setting personalized therapeutics closer to a clinical reality [17 - 20].

Conclusion

Convergence of personalized medicine and nanotechnology has dramatically altered the scenario of drug delivery to the most targeted, efficient, and patient-specific therapeutics. Nanocarriers, particularly liposomes, nanoparticles, and proniosomes, have dramatically shifted the scenario to better bioavailability, stability, and precision of drugs. Liposomal drug delivery system presents a higher encapsulation efficiency, controlled release, and increased circulation time; PEGylation and surface modification add these properties to targeting diseases specifically. Naso-pulmonary and oral drug delivery innovation comprises of liposomal inhalation therapy, effervescent tablets, and mouth-dissolving films. Other promising alternatives are proniosomes that show better stability and retention for drugs over liposomes and surpass many of the deficiencies associated with liposomes in practical use. Hybrid nanocarrier systems would best combine the best of two worlds for the approaches-vesicular and non-vesicular-and move multifunctional and precision-based therapeutics to prominence. Overcoming resistance by liposomal antibiotics is excellent, but herbal drug delivery through nanocarriers shows higher bioavailability along with long, arduous journeys towards clinical translation, targeting areas such as scalability, biocompatibility, and frameworks for regulation. The pipeline now includes AI-based formulations, gene-editing nanocarriers, and biomimetic drug transport systems that are certain to catapult personalized nanomedicine to the mainstream of clinical usage.

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