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"FROM PILLS TO PARTICLES: A COMPARISON OF TRADITIONAL DRUG DELIVERY WITH LIPOSOMAL AND GOLD NANOPARTICLE SYSTEMS"

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***Abstract**: This research compares two types of nanoparticle-based drug delivery systems: **liposomes** and **gold nanoparticles (AuNPs)**. These systems were evaluated for their drug targeting ability, safety, cost, and clinical usefulness. Compared to traditional methods like pills and injections, nanoparticles can deliver drugs more precisely and reduce side effects. The study found that **liposomes are better for general use**, while **gold nanoparticles are more effective for advanced treatments like cancer therapy**. This comparison highlights the future potential of smart drug delivery to improve patient care, especially in developing countries like Uzbekistan.*

***Keywords:** Nanoparticle-based drug delivery, liposomes, gold nanoparticles (AuNPs), smart drug delivery systems, targeted therapy, biocompatibility, cancer treatment, Uzbekistan healthcare*

1. Introduction

A drug delivery system (DDS) is defined as a formulation or a device that enables the introduction of a therapeutic substance in the body and improves its efficacy and safety by controlling the rate, time, and place of release of drugs in the body. This process includes the administration of the therapeutic product, the release of the active ingredients by the product, and the subsequent transport of the active ingredients across the biological membranes to the site of action. The term therapeutic substance also applies to an agent such as gene therapy that will induce in vivo production of the active therapeutic agent. Gene therapy can fit in the basic

and broad definition of a drug delivery system.[1] Drug delivery, the ability to make sure that a pharmacologically active substance arrives at a relevant in vivo location while minimizing toxicity, has become a central topic in pharmaceutical research and development. Achieving such a task requires that the problems presented by undesirable physicochemical properties such as low solubility or high lipophilicity are overcome using formulation technology. That candidate molecules have such properties is not surprising, or even avoidable, given the location that many biological targets have in the body, i.e., highly hydrophobic cell membranes or behind alternating layers of hydrophilic and hydrophobic tissues. In addition, the similarity in active sites among likely targets, e.g., kinases, means that the structural differences between a compound that is usefully active and one that is toxic are very slight – to the point where targeted delivery is the only way a practical therapeutic index can be obtained.[2] By virtue of their unique physicochemical properties, nanoparticles have shown promise in delivering a range of molecules to desired sites in the body. To develop safer and more effective therapeutic nanoparticles, researchers have designed novel multifunctional nanoparticle platforms for cell/tissue-specific targeting, sustained or triggered drug-delivery, co-delivery of synergistic drug combinations, etc. Advances in biocompatible nanoscale drug carriers such as liposomes and polymeric nanoparticles have enabled more efficient and safer delivery of a myriad of drugs. Advantages in nanoparticle drug delivery, particularly at the systemic level, include longer circulation half-lives, improved pharmacokinetics and reduced side effects. In cancer treatments, nanoparticles can further rely on the enhanced permeability and retention effect caused by leaky tumor for better drug accumulation at the tumor sites. These benefits have made therapeutic nanoparticles a promising candidate to replace traditional chemotherapy, where intravenous injection of toxic agents poses a serious threat to healthy tissues and results in dose-limiting side effects. The use of such nanoparticles as delivery vehicles ensures that their cargo exerts its effect only inside the targeted cells. The compounds used in cancer chemotherapy are often highly toxic to many cell types, so targeting is crucial to minimizing collateral damage to healthy bystander cells.

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Efficient targeting thus significantly lowers the risk of serious side-effects, while allowing the dose required for a meaningful clinical response to be reduced. The primary goals for research of nano-bio-technologies in drug delivery include:

✓More specific drug targeting and delivery,

✓Reduction in toxicity while maintaining therapeutic effects,

✓Greater safety and biocompatibility, and

✓Faster development of new safe medicines.[3]

Drug delivery systems (DDS) improve the administration and efficacy of pharmaceutical compounds including antibodies, peptides, vaccines, drugs and enzymes, among others. Oral pills and injections represent the most common mode of administering drugs today. A majority of small molecule drugs are delivered by pills. Tens of billions of pills are annually consumed worldwide for aspirin alone. Injections remain the primary mode of administering proteins and peptides. More than 10 billion injections are performed each year worldwide.Oral pills offer convenience of pre-determined and measured doses, portability, defined dosing times and the overall non-invasive nature of administration. However, they are also limited by the inability to deliver larger therapeutic molecules such as proteins. Injections, on the other hand, are able to deliver macromolecules, but are limited by their invasive nature and inappropriate use. Collectively, simple pills and injections are unable to meet many advanced therapeutic needs including targeting, broad applicability to macromolecules and on-demand activation. While not all pharmaceutical molecules require these abilities, many do. These limitations have given rise to substantial research focused on the development of novel DDS.[4] Smart DDSs" is determined as the process that the drugs are not released before reaching target tissues/ organs (or with extremely slow rate), and only released with proper rates at the sites of action. Although the drug molecules themselves sometimes can be smart components, here we primarily discuss about smart DDSs by means of nanotechnology to carry the drug molecules. The delicate design of smart nanoplatform enables the release of payloads at specific tissues in systemic administration. Currently, the drug-loaded nanoplatform ensures that the drug will

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not freely extravasate during the blood circulation, but only release at the targets where the nanocarriers accumulate by active or passive targeting strategy. These elaborately designed smart or stimuli-responsive nanoplatforms can respond to endogenous and/ or exogenous stimulus. The endogenous triggers such as pH variations, hormone level, enzyme concentration, small bio-molecules, glucose or redox gradient[5,6,7]

This paper will compare traditional drug delivery systems, such as oral pills and injections, with advanced nanoparticle-based systems—specifically liposomes and gold nanoparticles—to evaluate their effectiveness, safety, and potential in modern medicine. **2. Methods**This research was conducted using the **literature review method**. I collected scientific articles, white papers, and review papers from trusted sources such as **ScienceDirect**, **PubMed**, **Google Scholar**, and official pharmaceutical publications. I focused on research published between **2010 and 2024**, especially those discussing **liposomal and gold nanoparticle drug delivery systems**. Over **15 academic sources** were selected based on relevance, simplicity of explanation, and scientific credibility. I also reviewed **one textbook chapter** and **two white papers** (from LexInnova and Pfizer) for industrial insight. The collected data was then compared based on:

Targeting ability

Release behavior

Safety and side effects

Cost and complexity

Clinical use and approvals

No laboratory or experimental data was generated, and no surveys or simulations were conducted. All findings are based on published studies and expert-reviewed scientific literature.

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3. Results Comparison Table: Liposomes vs. Gold Nanoparticles in Drug Delivery Systems

Feature	Liposomes	Gold Nanoparticles (AuNPs)
Targeting Ability	High – Can be modified with ligands for active targeting	Very High – Easily functionalized for specific cell types
Drug Release Control	Moderate – Some control via lipid composition	High – Responds to stimuli (e.g., heat, light) for precise release
Biocompatibility	Very biocompatible – composed of natural or synthetic lipids	Good – Generally safe, but some concerns at high doses or long-term exposure
Toxicity / Safety	Low toxicity	Potential toxicity depending on particle size, shape, and coating
Cost & Production	Lower cost – Already scaled for clinical use	Higher cost – Expensive raw material (gold) and complex production process
Clinical Use	Widely approved – Used in FDA-approved drugs (e.g., Doxil)	Still in trials – Used in research and some early-stage clinical applications
Stability	Less stable in blood unless modified	Highly stable – Resistant to degradation

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Drug Capacity	Can carry both water-soluble and fat-soluble drugs	Limited capacity – Often used for surface-bound drug attachment
Stimuli-Responsive	Some – With chemical modifications (e.g., pH-sensitive liposomes)	Strong – Responds to pH, light, heat, redox changes
Size Range	50–200 nanometers	2–100 nanometers (precisely tunable)

*This comparison reveals that **both liposomes and gold nanoparticles** are highly promising smart drug delivery platforms, but they have different strengths. **Liposomes** are more **clinically established**, **cost-effective**, and **biocompatible**, making them ideal for general drug delivery applications. However, they can be unstable in circulation and offer limited control over drug release unless modified.*

*On the other hand, **gold nanoparticles** excel in **targeting precision**, **stimuli-responsive release**, and **stability**, but they are more expensive to produce and are still under **clinical evaluation** for safety. Their ability to respond to light or heat makes them especially promising for **cancer therapy**. [Table 1]*

4. Discussion

Nanoparticles have introduced a new generation of smart drug delivery systems. Among them, **liposomes** and **gold nanoparticles (AuNPs)** are two of the most researched. Each has unique strengths and weaknesses that make them suitable for different medical uses.

Liposomes are made from lipid layers, similar to the membranes of human cells, which makes them **very biocompatible and safe**. They are already used in approved medicines like **Doxil** (for cancer) and **AmBisome** (for fungal infections). Their strengths include the ability to carry both water- and fat-soluble drugs and being relatively cheap to produce. However, they may **degrade quickly in the**

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bloodstream and often need surface modifications to stay stable and avoid being removed by the immune system.

Gold nanoparticles, on the other hand, are very **stable** and can be **precisely targeted** to diseased tissues. They can also respond to **external triggers** like light or heat to release the drug exactly when needed. This makes them especially useful for **cancer treatments**, such as **photothermal therapy**. But their **production is expensive**, and they are still under investigation for long-term **toxicity** and safety in humans. Many gold NP-based treatments are still in **clinical trials**.

In terms of **when to use each**:

- **Liposomes** are better for **standard drug delivery**, especially when cost and safety are important.
- **Gold nanoparticles** are more useful for **precision targeting**, **cancer treatment**, or **stimulus-triggered release**.
- Compared to **traditional pills and injections**, both nanoparticle systems offer significant advantages. While pills release drugs **everywhere** in the body, and injections often require **repeated dosing**, smart nanoparticles allow drugs to be **delivered exactly to the diseased tissue**, which can reduce side effects and improve effectiveness.

However, there are still **limitations**. Many nanoparticle systems are **not yet approved** by medical regulators, especially gold-based systems. The **cost of production**, **difficulty in large-scale manufacturing**, and **lack of long-term safety data** are still major challenges. In addition, responses to internal triggers like pH or enzyme levels can vary from person to person, making it hard to ensure consistent results.

This research is important because smart DDS can help us move toward more **personalized, efficient, and safer treatments**. [7,8,9]

5. Conclusion

In this research, I explored the differences between traditional drug delivery methods and smart systems using **nanoparticles**, especially **liposomes** and **gold nanoparticles (AuNPs)**. I found that while both nanoparticles offer advanced ways

to deliver medicine more effectively, they each have unique strengths and weaknesses depending on the medical need.

Liposomes are better suited for general drug delivery because they are safe, cost-effective, and already approved in many clinical treatments. They are especially helpful for carrying both water- and fat-soluble drugs. In contrast, **gold nanoparticles** are better for highly targeted or stimulus-triggered therapies, such as cancer treatment, because of their stability, precision, and ability to respond to light or heat.

The future of drug delivery is likely to move more toward **personalized and smart systems**, where medications are released only at the site of disease, reducing side effects and improving patient outcomes. However, more research is needed to solve issues like cost, long-term safety, and large-scale production.

For countries like **Uzbekistan**, where rural hospitals may not have access to advanced healthcare technologies, smart drug delivery systems could offer a way to improve treatment with **fewer doses, fewer side effects**, and **less need for repeat visits**. In the long run, these systems could make healthcare more efficient and accessible, especially in areas with limited resources.

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