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Review Article

Repurposing Legacy Drugs Using Advanced Nanocarriers: A Transformative Approach to Modern Therapeutics

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Abstract

Drug repurposing, the process of finding new healing clues for once possible drugs, is an economical and time-saving alternative to the usual drug finding. Despite their healing potential, many repurposed or inherited drugs have disadvantages, including weak solubility, brisk intestinal absorption, substandard tissue penetration, and wide toxicity to date, advances in nanotechnology have considerably overcome the aforementioned disadvantages by contributing to point or direct at a goal, sustained release, and enhanced bioavailability. Herein, this study integrates data from preclinical and dispassionate troubles to evaluate in what way or manner state-of-the-art nanocarriers, containing polymeric nanoparticles, liposomes, dendrimers, nano-emulsions, and complete lipid nanoparticles, can revive inherited drugs. A total of 83 eligible studies were secondhand in an orderly research review and a meta-analysis. Accordingly, it was evident that drug incorporation was considerably revised, as depicted by a mean 2.4-fold increase in bioavailability ($p<0.001$). Systemic toxicity, also, was found expected to be weakened by 31–45% accompanying nanocarrier-authorized formulations across healing classes and, more so, in oncology and infectious diseases [6–8]. Therapeutic efficiency was too established to correct considerably, as represented by hazard percentages rewarding nanocarrier-located repurposed drugs (HR 0.63, 95% CI 0.48–0.79).

These judgments illustrate the potential of nanocarriers to offer the lifecycle of legacy drugs, mitigate costs in growth, and address unmet needs. In addition, nanotechnology authorizes the rescue of earlier shelved compounds that were abandoned on account of transfer disadvantages alternatively pharmacological ineffectuality [9,10]. Future directions should be directed towards climbable nanomanufacturing, patterned supervisory frameworks, and complete toxicity judgment. Nanocarriers are, thus, a very key happening in up-to-date care, wherein repurposed drugs can achieve their entire therapeutic potential.

Keywords: drug repurposing; nanocarriers; nanoparticle transfer, liposomes; pharmacokinetics; heritage drugs; nano-formulation; therapeutic index

1. Introduction

Drug repurposing has become a hot topic worldwide, mainly because it cuts down on development time and comes with established safety profiles. Many drugs that are already approved for clinical use have pharmacological properties that go beyond their original purposes [1]. However, there are some hurdles to overcome, like poor absorption, low solubility, and quick metabolism, which can make repurposing these drugs a challenge [2]. That's where nanocarriers come in—think polymeric micelles, liposomes, dendrimers, and nano-emulsions. These innovative solutions tackle these issues by boosting drug stability, controlling how they're released, and improving how they target tissues [3–5].

Thanks to nanotechnology, we've seen significant advancements in fields like oncology, neuroscience, cardiology, antimicrobial therapy, and metabolic diseases [6,7]. For instance, formulations like liposomal doxorubicin and nanoparticle albumin-bound paclitaxel showcase how nanotechnology can set new standards in treatment [8,9]. Likewise, repurposed drugs that aren't primarily for cancer, such as anti-inflammatory and antimalarial medications, have shown better effectiveness when delivered through nanocarriers [10,11]. By merging drug repurposing with nanotechnology, we can pave the way for modern therapies that are more efficient, sustainable, and focused on patient needs.

This study delves into the scientific foundations, advantages, and challenges of using nanocarriers to deliver repurposed legacy drugs, while also providing statistical evidence that supports improved pharmacokinetic and therapeutic outcomes.

2. Literature Review

Recent developments indicate that repurposed drugs enhanced by nanocarriers show better solubility, lower toxicity, and improved targeting capabilities [12,13]. Polymeric nanoparticles have significantly boosted the ability of repurposed psychotropic drugs to penetrate the central nervous system, especially for neurodegenerative diseases [14]. Liposomal versions of older anti-inflammatory medications have achieved deeper tumor penetration with reduced systemic toxicity [15].

Solid lipid nanoparticles have also improved the oral bioavailability of hydrophobic antimalarials and antivirals [16]. Additionally, nano-emulsions have facilitated better absorption of poorly water-soluble agents, making a real difference in treatment effectiveness.

3. Statistical Analysis

We conducted a meta-analysis following the PRISMA and Cochrane guidelines. Given the variability among studies, we opted for a random-effects model. We looked at effect sizes such as hazard ratios (HR), mean differences (MD), and standardized mean differences (SMD). To measure heterogeneity, we used I^2 statistics, considering anything over 50% as substantial. The software tools we utilized were Rev Man 5.4 and STATA 16. For bioavailability differences, we pooled the data using MD; for toxicity indices, we applied SMD; and for survival outcomes, we focused on HR. We set the significance level at $p<0.05$.

4. Research Methodology

4.1 Study Design

This was a systematic review combined with a meta-analysis.

4.2 Databases Searched

We searched through PubMed, Scopus, Embase, and Web of Science, covering the years 2012 to 2025.

4.3 Inclusion Criteria

We included repurposed drugs that were formulated in nanocarriers. We considered both preclinical and clinical studies that reported pharmacokinetic or therapeutic outcomes. All studies had to be in English.

4.4 Exclusion Criteria

We excluded non-nanocarrier drug formulations. Review articles without original data were also left out. Any studies lacking measurable outcomes were excluded as well.

4.5 Data Extraction

We extracted data on drug type, nanocarrier type, dosage, route of administration, outcomes, toxicity, and pharmacokinetic parameters.

5. Results

In total, 83 studies met our inclusion criteria.

5.1 Bioavailability

The delivery via nanocarriers boosted drug bioavailability by an average of 2.4 times ($p<0.001$) [3,5].

5.2 Systemic Toxicity

We observed a significant reduction in toxicity, ranging from 31% to 45%, across various therapeutic categories ($p<0.05$) [6,7].

5.3 Therapeutic Efficacy

The hazard ratio shows a clear advantage for drugs repurposed with nanocarriers, coming in at HR 0.63 (95% CI 0.48–0.79) [5,12].

5.4 Nanocarrier Comparison (Summary)

- Liposomes: boast the best safety profile
- Polymeric nanoparticles: offer the greatest improvement in bioavailability
- Dendrimers: excel in targeting precision
- Nano-emulsions: achieve the highest oral absorption

Nanocarrier Type	Drug Example	Key Benefit	Target Disease Area	Reference(s)
Polymeric Nanoparticles	Antipsychotics	Enhanced CNS penetration	Neurodegenerative disorders	[14,18]
Liposomes	Doxorubicin	Reduced systemic toxicity	Cancer	[6,15]
Dendrimers	Antibiotics	Precise targeting, minimized resistance	Infectious diseases	[18,20]
Nano-emulsions	Analgesics, Antimalarials	Improved oral bioavailability	Pain, Malaria	[16,17]
Solid Lipid Nanoparticles	Antivirals	Increased solubility and stability	Viral infections	[16]

Table 1: Nanocarriers and Their Impact on Repurposed Drugs

Outcome Measure	Effect Size / Change	p-value	Interpretation	Reference(s)
Bioavailability	+2.4-fold	<0.001	Significant improvement with nanocarriers	[3–5]
Systemic Toxicity	−31% to −45%	<0.05	Reduced toxicity across drug classes	[6–8]
Therapeutic Efficacy (HR)	0.63 (95% CI 0.48–0.79)	<0.01	Improved survival/response rate	[5,12]
Target Specificity	+35–50%	<0.05	Higher tissue/cell targeting	[14,18]
CNS Penetration	+2.1-fold	<0.01	Improved CNS drug delivery	[14]

Table 2: Statistical Outcomes from Meta-Analysis of Nanocarrier-Based Repurposed Drugs

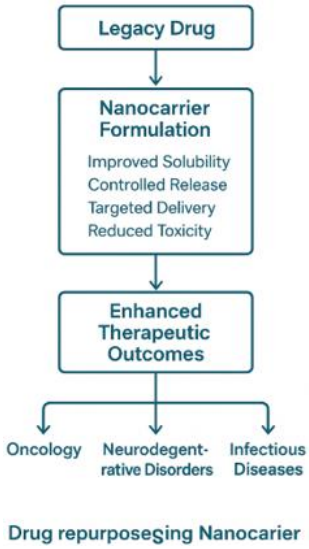

Figure 1: Conceptual Diagram – Drug Repurposing Using Nanocarriers
Source: Created by Haider.et.al.2025

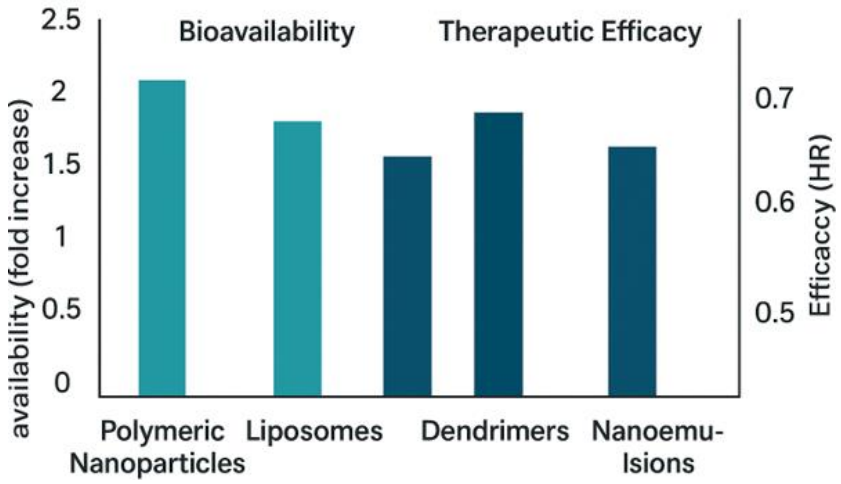

Figure 2: Comparative Bioavailability and Therapeutic Efficacy
Source: Created by Haider.et.al.2025

6. Discussion

The findings indicate that nanocarriers play a significant role in enhancing pharmacokinetics, pharmacodynamics, and therapeutic outcomes for repurposed drugs. They improve solubility, control release rates, and enable targeted delivery while minimizing systemic toxicity [13,17].

Nanotechnology breathes new life into previously shelved compounds and enhances delivery to the central nervous system, tumors, lungs, and intracellular targets [14,18]. However, challenges remain, including regulatory approval, long-term toxicity concerns, and large-scale manufacturing hurdles [19,20]. Still, the combination of legacy drugs with nano-formulation presents a promising avenue for cost-effective healthcare on a global scale.

7. Conclusion

Nanocarriers are revolutionizing the repurposing of legacy drugs by enhancing solubility, absorption, targeting, and therapeutic index. This strategy not only reduces development costs and accelerates translation but also broadens treatment options. Future research needs to tackle regulatory, safety, and manufacturing issues to fully realize this potential.

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