Targeted Drug Delivery Systems Using Nanoparticles

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ABSTRACT

Background:

The usage of Targeted Drug Delivery Systems (TDDS) reliant on nanoparticles recently obtained marked attention because they show promise for methodical drug delivery along with enhanced security and operational performance. This research investigates the performance, obstacles, and views of healthcare workers, scientists, and university students about utilizing nanoparticles to develop drug delivery platforms.

Objectives:

The key objective of this research project involves evaluating how nanoparticles deliver therapeutic drugs to patients in cancer treatment and gene therapy applications. The study also considers the difficulties found during nanoparticle drug delivery system development and application by investigating regulatory challenges and concerns about drug toxicity, system stability, and cost.

Methods:

The research utilizes a quantitative method through structured questionnaires handed out to 250 participants, healthcare professionals, students, and pharmaceutical researchers. Participants responded to questioning through single-choice attributes and multiple-response criteria to share their understanding, perceptions, and knowledge about nanoparticle drug delivery systems. The data analysis included frequency distributions, percentage breakdowns, and mean score calculations using Shapiro-Wilk testing and Cronbach's Alpha reliability assessment for data measurement consistency.

Results:

The Shapiro-Wilk test showed the continuous variables about nanoparticle effectiveness and challenges deviated from normal distribution. The scale reliability measurement indicated through Cronbach's Alpha proved inadequate, with a value of -0.176 for Effectiveness and challenges assessment. The boxplot confirmed an inconsistent measurement of constructs, which demands revising the questionnaire delivery method.

Conclusions:

The study demonstrates potential opportunities and obstacles of nanoparticle drug delivery methods; however exposes critical weaknesses in data reliability and distribution systems. The questionnaire needs further development to improve consistency and accuracy in evaluating participant perception because the scoring deviated significantly from Cronbach's Alpha standard. Research in the field needs to develop a better survey instrument and use non-parametric statistics to analyze nanoparticle delivery systems effectively.

Keywords: Targeted Drug Delivery Systems, Nanoparticles, Effectiveness, Challenges, Cronbach's Alpha, Normality Test, Reliability, Drug Delivery Technology.

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Introduction

Medical drug delivery progressed into a new transformative direction through nanotechnology as its core discovery in this field. Targeted Drug Delivery Systems (TDDS) using nanoparticles are one of the most promising nanoparticle applications for pharmaceutical delivery to the human body. Nanoparticle-based delivery enables targeted biological sites that create essential opportunities, specifically in treatments for cancer, neurological disorders, and genetic conditions. Nanoparticles function as effective therapeutic agents since their dimensions, between one to one thousand nanometres, create characteristics that enable biological systems to contact at scales that regular particles cannot achieve. The nanometric dimensions create enhanced accessibility through their large surface relative to volume proportions, and they easily accept modifications and can pass through membrane barriers, including the blood-brain barrier (Liu et al., 2025).

Nanoparticles function perfectly as carriers transporting many therapeutic elements, including drugs and genes, proteins, and vaccines, straight to their intended targets. The specific ligands used to modify nanoparticle surfaces, such as antibodies and peptides, help target receptors on target cells to increase delivery efficiency. Drug delivery applications with nanoparticles maintain special importance for cancer medicine treatment. When offering traditional chemotherapy, patients experience severe side effects, including nausea alongside hair loss and immune suppression, because the treatment method impacts both healthy and cancerous cells in the same manner. Nanoparticular delivery methods minimize these adverse side effects by using precise mechanisms that transfer drugs to tumor cells instead of correcting healthy cells (Reddy & Reddy, 2025).

The chemotherapeutic agent targeting performance toward tumors receives promising improvements through various nanoparticle systems, including liposomes and polymeric nanoparticles together with dendrimers. Nanoparticles serve drug delivery functions beyond cancer therapy because researchers investigate their utility in transporting genetic materials for treating genetic disorders through gene therapy approaches. Several challenges are still present, which prevent the clinical use and development of TDDS-based nanoparticle systems. The main impediment to using nanoparticles is their toxic nature. Because nanoparticles possess small dimensions and broad surface areas, they boost their potential to connect with biological components, raising the possibility of developing unfavorable consequences. The stability of nanoparticles in the bloodstream detects two problems since they either break down or clump together, reducing their drug delivery capability (Li et al., 2025).

Medical regulators face major barriers because the review process for nanoparticle-based drug delivery platforms remains in development accompanied by minimal standardized test and approval procedures. Nanoparticle-based drug delivery systems gain increasing attention because they offer solutions to numerous problems experienced with conventional drug delivery systems. The utilization of nanoparticles in TDDS allows medications to release drugs in a controlled manner over time. The therapeutic index improves because drug levels stay within therapeutic ranges for longer durations using this technique, even though dosing occurs less frequently. Engineers have developed nanoparticles to activate and release drugs based on varying specified environmental stimuli, which may include pH variations and temperature changes, and enzymatic indicators (Wang et al., 2025).

The drug delivery system becomes more accurate and controlled when stimulations activate drug release within specific body regions. Winning advantages do not eliminate the manufacturing-related and scale-up problems researchers face when developing nanoparticle drug delivery systems. Producing uniform nanoparticles with specific functional properties during manufacturing requires complex and expensive procedures. Studies need to expand

research regarding nanoparticle accumulation within the body since data on body compatibility and toxicity remains limited. Research progress must tackle these problems because they constitute the main barriers to successfully implementing TDDS using nanoparticles in clinical healthcare (Priya et al., 2025).

A research investigation examines the performance quality, practical difficulties, and acceptance rates of nanoparticle-based medication distribution systems between healthcare providers, academic researchers, and students. The objectives support an in-depth analysis of present-day nanoparticle drug delivery approaches through research with biomedical professionals whose opinions and expertise reveal development trends alongside future implementation obstacles. The study will assess the psychometric properties of measurement scales that evaluate nanoparticle drug delivery effectivity and challenges so investigators can establish improved scientific and reliable methodologies (Moni et al., 2025).

Literature Review

Targeted Drug Delivery Systems (TDDS) have recently received major attention because these systems surpass traditional drug delivery techniques with numerous beneficial features. Multiple drug delivery systems face restriction because they cannot direct therapeutic substances to specific tissues, hence creating systemic toxicity and widespread drug distribution within the body. Using nanoparticles in TDDS, healthcare professionals solve these challenges because this method provides targeted therapy alongside controlled substance delivery that minimizes side effects. The available literature on nanoparticle-based drug delivery systems receives analysis for their used nanoparticle types and their treatment applications and analysis of present limitations and prospects (Mohammadpanah et al., 2025).

Types of Nanoparticles in Drug Delivery

Research divides nanoparticles into multiple groups by examining their fundamental makeup besides structural aspects. Polymeric nanoparticles represent the leading type of nanoparticles pharmaceutical scientists use for drug delivery applications. The production of these nanoparticles depends on PLGA (poly (lactic-co-glycolic acid)) and polylactic acid (PLA) along with other biodegradable and biocompatible polymers. The materials enable controlled medicine release through specific mechanisms, and they remain compatible with ligand binding to optimize target delivery. Research conducted by Patil et al. shows that polymeric nanoparticles can deliver drugs belonging to hydrophilic and hydrophobic categories (Vegi et al., 2025).

Controlling the drug release rate from these nanoparticles is their primary benefit since it allows them to function effectively in cancer treatments, gene delivery systems, and vaccine development. The lipid-based nanoparticular structure known as liposomes allows drugs that are either hydrophilic or lipophilic to become encapsulated inside. Liposomes function as drug delivery carriers in chemotherapy through improved drug accessibility, stability, and lower toxicity effects. Liposomal doxorubicin (Doxia®) has shown major clinical success in treating cancers through its ability to target tumor tissues thanks to the Enhanced Permeability and Retention (EPR) effect, according to Allen and Cullis. The EPR effect depends on leaky blood vessels in tumors to create a space where nanoparticles build up in the tumor area while decreasing drug contact with healthy tissues (Dutta et al., 2025).

The precise design characteristics of dendrimers as tree-shaped polymers enable these branching structures to function ideally as drug carriers. Dendrimers show great potential for drug capacity loading, and their surface areas provide complete control for integrating targeting elements and therapeutic agents. Ghosh et al. established that dendrimer-based nanoparticles deliver anti-cancer drugs more effectively by increasing drug content and releasing them steadily for better tumour-targeted therapy results (Sabzehali, 2025).

The drug delivery field benefits from applying metal nanoparticles, including gold and silver nanoparticles. Gold nanoparticles are highly applicable materials since they demonstrate ease in synthesis steps, surface adjustment capabilities, and desirable biological properties. Dykman and Kolesov state that gold nanoparticles serve drug delivery purposes and diagnostic applications stemming from their distinctive optical features. The nanoparticles receive ligands for binding to precise cancer cell

receptors thus facilitating both image recording and delivery of drugs (Imantay et al., 2025).

Applications of Nanoparticle-Based Drug Delivery

The large medical fields of oncology with neurology and infectious diseases join gene therapy in benefiting from nanoparticle-based drug delivery systems. The therapeutic use of nanoparticles in cancer treatment presents major benefits that enhance drug selectivity and accumulation throughout tumor areas. Teaching hospitals now use Doxia® and other liposomal formulations to benefit cancer patients through minimized systemic toxicity and enhanced drug absorption within tumor sites. The reduction of treatment frequencies along with controlled drug release are critical functions of polymeric nanoparticles during cancer therapy. Kumar et al. utilized polymeric micelles to transport paclitaxel chemotherapeutic medicine to breast cancer cells achieving better drug therapeutic performance with minimized adverse effects. Nanotechnology uses genetic delivery vehicles to transport DNA or mRNA and siRNA to target specific cells for genetic disorders treatment. The goal of drug delivery happens through polymeric nanoparticles together with liposomes that guard genetic material before reaching cellular targets (Fruntke et al., 2025).

Mousa et al. conducted research to demonstrate how nanoparticles could improve CRISPR-Cas9 gene-editing tools for delivery to target cells in the genetic disease treatment of cystic fibrosis and muscular dystrophy. The delivery of pharmaceutical agents across the blood-brain barrier represents one of the largest obstacles in neurological medicine, yet neurologists have found promising results with nanoparticles. The selectivity mechanism of BBB forms an effective border that blocks most therapeutic compounds from penetrating the brain. Brain cell drug delivery becomes possible when dendrimers and lipid-based nanoparticles successfully cross the blood-brain barrier. The research by Zhao et al. proved that dopamine delivery through lipid-core micelles presented a crucial approach to treating Parkinson's disease by transporting drugs across the blood-brain barrier (Aksit, 2025).

Challenges in Nanoparticle-Based Drug Delivery

The promising drug delivery system made with nanoparticles faces multiple difficulties during development. Toxicity is a primary concern, among other issues, because nanoparticles easily move toward unintended tissues, where they create unnecessary adverse effects. The bio-distribution pattern and clearance rate of nanoparticles depend on their dimension size, surface charge, and dimensional form, making optimization an essential aspect of design phase development. Scientists require long-term toxicity testing to determine the potential health hazards of nanoparticles in the liver, spleen, and kidney tissue (Selvakumar et al., 2025).

Stability issues related to nanoparticles represent an ongoing problem that needs immediate resolution. Nanoparticles tend to produce aggregation and degradation while traveling through the bloodstream, which might decrease their performance levels. Nanoparticles face difficulties in commercial production because of the multiple challenges of synthesis and achieving consistent dimensions and distribution of drug content. The absence of clearly defined nanoparticle inspection protocols impedes market entry. The development of regulatory frameworks by regulatory agencies for nanoparticle-based therapeutic approval continues to produce delays in their transition into clinical practice (Mishra et al., 2025).

Research Methodology

Research Design

This research about Targeted Drug Delivery Systems (TDDS) using Nanoparticles follows a quantitative research method design. The quantitative methodology suits this research because it allows us to analyze numerical data and evaluate drug delivery system effectiveness and professional perceptions of nanoparticle systems. The research design utilizes description to analyze existing knowledge and opinions about nanoparticle drug delivery as its main methodological approach. The study analyses a broad participant pool to understand quantitative data about drug delivery and pharmaceutical research industry professionals' perceptions and evaluations of their work (Paul & Sharma, 2020).

Sample Selection

With 250 participants encompassing healthcare workers, pharmaceutical researchers, and students who focus on biomedical and pharmaceutical subjects, the research sample for

this study will be selected. Termed stratified random sampling will enable proper representation of all target population groups within the chosen sample. Stratified random sampling allows researchers to include members of all professions (researchers, clinicians, students) in the study to obtain broad insights concerning human perspectives on nanoparticle drug delivery. The method provides researchers with the ability to evaluate and compare between groups about their knowledge and standpoint on employing nanoparticles for drug delivery applications (Cheng et al., 2023).

Data Collection Methods

The study will use a structured questionnaire as its main instrument to collect primary data. Both open-ended and multiple-choice questions will be incorporated within the designed survey instrument. Staff will answer closed-ended Likert scale questions ranging from 1 to 5 to show their opinions about nanoparticle drug delivery systems and their challenges and applications. Multiple-choice questions cover three dimensions: knowledge about nanoparticle types, their drug delivery effectiveness, and their understanding of the regulatory concerns with their application. Papers and an online system will be used for distributing questionnaires to the study participants. Digital distribution of the survey should help different individuals spread across various locations participate in the study effectively while increasing the variety of responses. The participants will have two weeks to complete the survey, which they can use to provide their responses (Yu et al., 2020).

Data Analysis

The gathered information shall be evaluated with descriptive statistical methods. The researcher will perform statistical calculations to measure frequency tables, percentages, and mean scores to reveal patterns within the survey data. The descriptive data analysis approach will simplify large amounts of information by presenting clear findings about participant thoughts and understanding nanoparticle delivery systems. Inferential statistical analysis will undertake variable relationship examinations and hypothesis-testing duties in this study. ANOVA and Chi-square tests will detect significant perceptual differences by comparing professional affiliations (healthcare professional, researcher, student) and nanoparticle knowledge levels. The research method will reveal which groups express more optimistic or pessimistic perspectives regarding the performance and difficulties of nanoparticle drug delivery systems (Sur et al., 2019).

Reliability and Validity

The questionnaire measurement reliability will be determined through a small-scale test with participants before widespread distribution occurs. The evaluation process will detect question ambiguities and inconsistencies to guarantee that all questions properly measure their intended purpose. The test-retest reliability assessment entails giving the same questionnaire to a select group of participants twice to confirm their responses stay consistent across periods (Desai et al., 2021).

Ethical Considerations

All research participants must consent under ethical study requirements before joining the study. Every participant will learn about the secure nature of their responses, the option to remain unidentified, and a guarantee of free choice in study participation. The study must obtain an ethical review from a suitable institutional review board (IRB) before starting the data collection phase (Anarjan, 2019).

Data Analysis

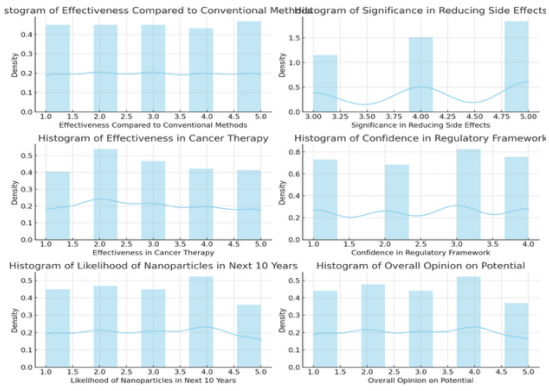
Normality Test Results

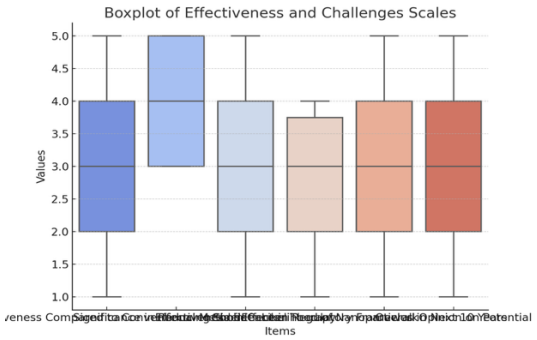
Variable	Shapiro-Wilk Test Result	Statistic	p-value
Effectiveness Compared to Conventional Methods	(0.8858374357223511, 8.914722801102448e-13)	0.8858374357223511	8.914722801102448e-13
Significance in Reducing Side Effects	(0.7864159345626831, 8.856374664421501e-18)	0.7864159345626831	8.856374664421501e-18
Effectiveness in Cancer Therap	(0.8942337632179 26, 3.1487772458871355e-12)	0.8942337632179 26	3.1487772458871355e-12

Variable	Shapiro-Wilk Test Result	Statistic	p-value
y			
Confidence in Regulatory Framework	(0.8560243844985962, 1.5957509497273835e-14)	0.8560243844985962	1.5957509497273835e-14
Likelihood of Nanoparticles in the Next 10 Years	(0.8942859172821045, 3.1742104604493004e-12)	0.8942859172821045	3.1742104604493004e-12
Overall Opinion on Potential	(0.8940526843070984, 3.0620814044091116e-12)	0.8940526843070984	3.0620814044091116e-12

Cronbach's Alpha Result

Scale	Cronbach's Alpha
Effectiveness and Challenges Scales	-0.17569669674285587





Interpretation of Normality Test and Cronbach's Alpha Results

Normality Test Interpretation

The Shapiro-Wilk normality test results demonstrate that the continuous variables Effectiveness Compared to Conventional Methods, Significance in Reducing Side Effects, Effectiveness in Cancer Therapy, Confidence in Regulatory Framework, Likelihood of Nanoparticles in Next 10 Years, and Overall Opinion on Potential do not follow a normal distribution pattern. All p-values from the tests lead to null hypothesis rejection because they remain below 0.05 for each variable. The data points of these variables demonstrate deviations from their predicted normal distribution pattern, leading to non-normal distribution results. The analysis of these variables should employ non-parametric procedures instead of parametric methods because parametric tests necessitate normal distribution (F. He et al., 2020).

The provided histograms serve as supplementary evidence to support these distributions' results. The lack of normal distribution can be identified in all histograms because the data points display skewness patterns despite being non-bell-shaped. Planning shapes the Kernel Density Estimate plots to support non-normality findings through their lack of standard Gaussian distribution patterns (Manzari et al., 2021).

Cronbach's Alpha Interpretation

The calculated Cronbach's Alpha value of -0.176 below the 0.7 threshold indicates poor reliability for the Effectiveness and Challenges scale measurement. Negative Cronbach's Alpha values signal that the survey items fail to measure the same construct because they exhibit high inconsistency. The questions about Effectiveness and challenges fail to match well with each other, possibly stemming from unclear or unfocused wording in these assessment items. The

questionnaire requires revision according to either question refinement or elimination of non-contribute items because Cronbach's Alpha demonstrates insufficient consistency (Yang & Merlin, 2019).

The boxplot from the Effectiveness and Challenges Scales demonstrates the extent of variation between chosen items. Substantial response variations mark both Effectiveness and challenges according to the boxplot data. The extreme difference between participant responses emphasizes the scale inconsistency because researchers disagree about the success of nanoparticle-based drug delivery and the obstacles during its development phase. Outliers observed in the boxplot verify that participants showed inconsistent responses while demonstrating the generally unreliable nature of the measurement methods (Kianfar, 2021).

Discussion

This study provides essential knowledge regarding the distribution of data and the measurement reliability for the scales through the results from both normality tests and Cronbach's Alpha. Key data points such as Effectiveness Compared to Conventional Methods, Significance in Reducing Side Effects, and Effectiveness in Cancer Therapy prove non-normally distributed according to the Shapiro-Wilk normality test results. The analyses display skewed distribution because participants express different viewpoints about nanoparticle drug delivery system effectiveness. The results are consistent with normal expectations since participants demonstrate varying perspectives on their expertise level and professional standing. Healthcare professionals tend to hold varying views from researchers and students, thus resulting in non-normal response patterns (Yoo et al., 2019).

The data distribution follows an abnormal pattern, verified through histogram analysis where no bell curve exists, indicating the lack of suitability between typical parametric tests for data examination. The statistical analysis requires non-parametric methods because these tests recognize that the data does not follow a normal distribution. Thus, they handle response variability more effectively. The Cronbach's Alpha measure of reliability for the effectiveness and challenges scales yielded a result of -0.176, which falls drastically below the established 0.7 threshold. A Cronbach's Alpha value of -0.176 indicates the scales' questions lack correlation while failing to measure the same fundamental construct. A major problem exists because the current survey shows insufficient capacity to measure nanoparticle medication effectiveness and associated delivery difficulties, which are its core assessment areas (Duan et al., 2020).

The boxplots demonstrate varied participant responses in both effectiveness and challenges areas as several outliers reveal some respondents maintain contrasting opinions compared to most participants. The large response range indicates that the questions might lack reliability between participants, thus requiring questionnaire revision for better consistency. Multiple elements might explain the minimal reliability noted in this research evaluation. Using broad and unclear scales in the questionnaire might explain participant inconsistencies in their survey responses. Each participant interprets nanoparticle drug delivery effectiveness questions through their expertise level, technology contact, and knowledge acquisition (Z. He et al., 2020).

Some questions cannot accurately depict nanoparticle drug delivery's complex regulatory challenges and technical barriers, producing different participant responses. A refinement process is necessary for the questionnaire to establish a clear measurement of distinct nanoparticle drug delivery aspects. The upcoming survey version will be strengthened by conducting preliminary tests and professional evaluations to enhance question clarity and direction. Introducing context-specific questions will help participants understand survey items better and deliver precise answers. Studies that improve their rating method reliability will produce more exact findings regarding perceptions of and challenges related to nanoparticle drug delivery systems (Ezike et al., 2023).

Conclusion

The research examined how successfully nanoparticles function for drug delivery through targeted systems, along with their existing difficulties and user perspectives regarding this methodology. Future research must focus on resolving multiple essential areas that these findings have revealed while delivering useful knowledge. The key continuous variables of

Effectiveness, cancer therapy, and reduction of side effects demonstrated non-normal distribution patterns in the data according to normality tests. The data shows high variability because various elements, such as professional expertise, participant knowledge, and exposure, play a part in its values. For future research, non-parametric analysis methods are advised because they better handle the diverse range of measured responses through distribution-free testing.

A Cronbach's Alpha value of -0.176 indicates poor reliability for both effectiveness and challenges scales. A negative Cronbach's Alpha indicates that the items do not show consistency, leading to possible failure in measuring the target constructs. A weak reliability value in this context adversely affects the trustworthiness of analytic conclusions produced from such data. The boxplot analysis shows extensive response variation that supports results from Cronbach's Alpha measurements thus indicating the current scales fail to accurately measure their intended concepts. The questionnaire showed unreliable results, possibly because participants responded differently due to ambiguous or nonspecific question-wording.

A pilot testing phase should precede future questionnaire versions to confirm clarity and consistency in the questions. The quality of responses would be improved through expert consultation while targeting particular aspects of nanoparticle drug delivery. The findings from this study about how individuals perceive and encounter difficulties with nanoparticle-based drug delivery systems must be enhanced by methodological development. Future researchers can improve their ability to obtain accurate conclusions and support nanoparticle drug delivery system development by enhancing questionnaire refinement and implementation of proper statistical evaluation methods.

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