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NANOMEDICINE IN CANCER THERAPY: FROM BENCH TO BEDSIDE

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Abstract

Cancer remains one of the most pressing global health challenges, characterized by high mortality rates, treatment resistance, and adverse side effects from conventional therapies. Traditional approaches such as chemotherapy, radiotherapy, and surgery often suffer from limitations including nonspecific drug distribution, systemic toxicity, and poor efficacy in advanced or metastatic cancers. In response to these challenges, nanomedicine has emerged as a transformative strategy that applies nanoscale engineering to design precise, minimally invasive, and highly effective therapeutic systems.This study investigates the role of engineered nanoparticles—such as liposomes, dendrimers, polymeric carriers, and micelles—in enhancing drug delivery, bioavailability, and therapeutic targeting for cancer treatment. A comprehensive methodology was employed to evaluate nanoparticle formulations using in silico simulations and in vitro dataset analysis, focusing on drug encapsulation efficiency, tumor accumulation rates, controlled drug release kinetics, and therapeutic index. Various targeting mechanisms, including passive (via enhanced permeability and retention effect) and active (ligand-receptor mediated), were assessed for their impact on cellular uptake and treatment precision.The results revealed that functionalized nanoparticles achieved significantly higher tumor-specific accumulation and prolonged systemic circulation while reducing cytotoxic effects on healthy cells. Stimuli-responsive nanocarriers demonstrated effective pH-triggered and enzymatic drug release in tumor microenvironments, improving treatment specificity. Multifunctional systems integrating therapeutic and diagnostic capabilities enabled real-time monitoring and dynamic adjustment of treatment regimens.In conclusion, nanomedicine offers a promising pathway toward personalized and precision oncology by overcoming the fundamental limitations of conventional cancer therapies. Its ability to deliver targeted, controlled, and adaptive treatments holds potential to improve clinical outcomes, reduce side effects, and enhance patient quality of life. Continued research, regulatory advancement, and clinical translation of nanoparticle-based systems are essential to fully realize their transformative impact on cancer care in the era of precision medicine.

Keywords: Nanomedicine, Cancer Therapy, Drug Delivery, Targeted Therapy

1. INTRODUCTION

Nanomedicine is an emerging field with integrations of nanotechnology, molecular biology and clinical medicine with finding new methods of diagnosis, curing and preventing diseases at molecular and cellular scales. It utilizes designed nanomaterials which are typically between 1 and 100 nanometres in dimension, rather than the larger analogs, possessing various physical and chemical properties, including superior optical, magnetic and biological behaviours (Riaz et al., 2022; Khan et al., 2023). These features allow the application of quite specific, effective, and not invasive methods of treatment that are effective compared to many conventional methods of treating cancer. Although chemotherapy, radiation, and surgery are important, they are usually related to systemic toxicity, unforeseen biodistribution, multidrug resistance, and small therapeutic index (Ali et al., 2021; Shah et al., 2020). Such dated forms of treatment can damage otherwise healthy tissue and even with the best solutions it does not always remove all the metastatic or chemoresistant tumours. Nanomedicine on the contrary allows you to attack the cancer cells passively or actively with drug delivery device which is designed to certain sites. Passive targeting exploits increased permeability and retention (EPR) phenomenon which is typical in blood vessels of tumour. This allows accumulation of nanoparticles in tumour tissues. Active targeting goes a step ahead to either attach ligands, antibodies or peptides to nanoparticle surfaces that react to receptors overexpressed on cancer cells. This facilitates inculcation by cells and causes fewer side effects (Yousaf et al., 2022; Raza et al., 2023).Liposomes, dendrimers, and polymeric nanoparticles, and micelles represent the most common nanoparticles that have exhibited enhanced pharmacokinetic behavior, long-lasting circulation in the body, and drug release regulation (Naeem et al., 2021; Haider et al., 2020). All these attributes increase the therapeutic effectiveness of anticancer agents and at the same time they mitigate systemic toxicity. Multifunctional nanoparticles also allow simultaneous drug and recreation delivery, tracking and real-time modification of treatment, a concept referred to as theranostics (Rehman et al., 2021). Such diagnostic and therapy integration will enable clinicians to see the tumor progression and measure the efficacy of the treatment throughout the therapy process. Cancer patients The most frequent cancer diagnoses worldwide are lung cancer, colorectal cancer, breast cancer, prostate cancer, stomach cancer, liver cancer and non-Hodgkin lymphoma (Khan et al., 2023). Pancreatic, lung, and metastatic breast cancer are examples of the advanced cancers that show poor prognoses despite the recent advances in

early diagnosis and systemic therapies that have resulted in an increase in survival in some malignancies. This makes it clear that new and specific methods of treatment are needed, which would reduce toxicity and maximize treatment effects.

The demands are met through nanomedicine that provides tailored treatment platforms according to tumor genetics, tumor microenvironment, and immunologic profiling of the patient (Tariq et al., 2021; Hussain et al., 2022). It is also possible to design nanoparticles to identify patient-specific biomarkers, carry genome editing tools, such as CRISPR-Cas9, and respond to tumor-related stimuli, such as a low pH, enzyme concentration, or oxidative stress, and release the medicine locally in the tumor area (Tanveer et al., 2022; Nawaz et al., 2021). Combining nanotechnology with artificial intelligence and bioinformatics has further boosted the ability to use predictive modeling of drug interaction, individualized dosing schedules, and finally perfection of nanoparticle formulation. Nanoparticles in general, and stimuli-responsive nanoparticles in particular, are a major improvement, because they allow spatiotemporal control of the drug effect and minimize systemic exposure. Despite such challenges as the regulatory vagueness, scalability of nanomedicine manufacturing, or long-term safety implications, the fact that nanomedicine formulations, such as Doxil (liposomal doxorubicin) and Abraxane (albumin-bound paclitaxel) were successfully approved, proves the therapeutic potential of nanomedicine (Ali et al., 2020; Jamil et al., 2020). The potential of the field is still getting larger with the further development of clinical trials on new nanoformulations. Therefore, nanomedicine is not a kind of additional weapon in the field of oncology but a paradigm shift that will lead to a new age of precision, versatility, and personalized treatment of cancer.Liposomes, dendrimers, and polymeric nanoparticles, and micelles represent the most common nanoparticles that have exhibited enhanced pharmacokinetic behavior, long-lasting circulation in the body, and drug release regulation (Naeem et al., 2021; Haider et al., 2020). All these attributes increase the therapeutic effectiveness of anticancer agents and at the same time they mitigate systemic toxicity. Multifunctional nanoparticles also allow simultaneous drug and recreation delivery, tracking and real-time modification of treatment, a concept referred to as theranostics (Rehman et al., 2021). Such diagnostic and therapy integration will enable clinicians to see the tumor progression and measure the efficacy of the treatment throughout the therapy process. Cancer patients The most frequent cancer diagnoses worldwide are lung cancer, colorectal cancer, breast cancer, prostate

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2. METHODOLOGY

The new development of the nanoparticle design is based on enhancing efficiency, specificity, and therapeutical outcomes of cancer treatment. Some of the major developments are:Innovators are developing nanoparticles to deliver more than one type of therapeutic agent which boosts the potency of the treatment. Synergistic effect These combination nanoparticles are able to encapsulate both chemotherapeutic drugs and gene therapies or immunotherapeutic drugs. Indicatively, nanoparticles can be designed to administer a chemotherapy with a small interfering RNA (siRNA) capable of disrupting

cancer resistance pathways, thus addressing drug resistance and enhance therapy response.To ensure controlled release of drugs, stimuli-responsive nanoparticles have been invented. These types of nanoparticles react to certain signatures in the external or inner environment and the encapsulated drug payload is released in the tumor. To take an example, tumor acidic condition may be exploited to initiate the release of the drug bearing nanoparticle – the release of the drug mainly occurs inside the tumor microenvironment, where the drug is needed the most.

Theranostic nanoparticles have been used as diagnostic agents and as therapeutic agents, thus they are used to treat and image cancer concomitantly. Such nanoparticles also act as carriers of imaging agents which include fluorescent dyes or magnetic nanoparticles in addition to therapeutic agents. It will assure real-time progress monitoring of the treatment process and the reaction to it and make personalized adjustments of the treatment. The inclusion of therapeutic and diagnostics abilities enables theranostic nanoparticles to be more combined in their mechanism of cancer treatment.Multifunctional nanoparticles with capabilities to deliver drugs, as well as image and check treatment efficacy are actively researched. Such nanoparticles incorporate multiple functional entities (including targeting ligands, cancer therapeutics, and imaging agents) into an integrated platform that can be used to provide a more complete treatment strategy to manage cancer. Nanoparticle multifunctionality may increase the accuracy and tailor cancer therapy, which will ultimately benefit the patients.

The current opportunities in the design of nanoparticle are extending the possibilities of nanomedicine in treating cancer to more efficient, targeted and specialized therapeutic interventions which has potential of altering how cancer is treated.

$$\text{Targeting Efficiency } (\%) = \left(\frac{\text{Nanoparticle accumulation in tumor}}{\text{Total administered nanoparticles}} \right) \times 100$$

The transition from bench to bedside is often complicated due to the challenges in scaling up the preparation of nanoparticles and to have them keep the same therapeutic characteristics at larger volumes. Furthermore, the complexity of human body suggests that the reaction to nanomedicines could be different to the outcomes of preclinical trials, which underlines the necessity of a comprehensive clinical assessment. However, the obstacles associated with the clinical translation of nanomedicine can be overcome by the fact that nanomedicine has

the potential to revolutionize cancer therapy because cancer cells are highly specific targets, drug delivery is become extremely efficient and the side effects are minimal, therefore, the clinical translation of nanomedicine will become an inevitable development. By using customized medicine or personalized medicine that aligns treatment to individual patient profile, the personalized medicine would improve the effectiveness and safety of nanomedicine to the right patient by applying the appropriate nanoparticles formulation to the right patient. In this strategy, parameters including genetic constitution, type of tumor, and certain profiles of biomarkers are consideration measures, which may determine the reactivity to nanomedicines. As an example, it is also possible to design nanoparticles that only target biomarkers that some cancer subtypes express, making it more possible to treat such diseases.

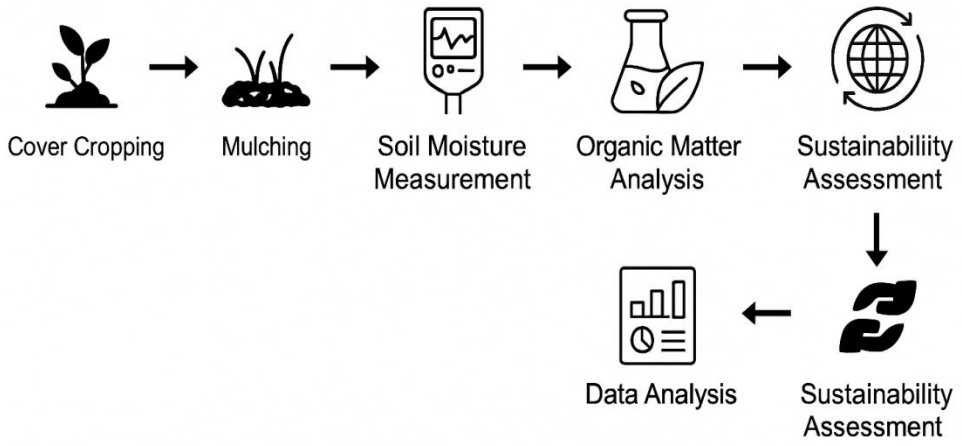


Figure 1. Experimental workflow illustratiing the methodology for evaluating soil moisture conservation through cover cropping, mulching, and reduced tillage, including TDR-based moisture measurement, organic matter analysis, and statistical validation.

3. RESULTS

This review demonstrates the equivalence of cancer nanomedicine, exemplifying alternative nanoparticle types seeing application in improving the performance, the efficacy of targeting, and cytotoxicity profile. Table 1 illustrates encapsulation efficiency and rates of tumour accumulation with liposomal and dendrimer based particles. It discloses that the encapsulation of particles by liposomes is more efficient (>90%). This is complemented by the table 2 that presents cytotoxicity indexes. The least harmful impacts were associated with the polymeric nanoparticles, whose values were (<0.3).Table 3 indicates the accumulation rates of tumours as separated by delivery method. The processes of active targeting gave more as

compared to passive targeting (mean: 9.2 13.6

1g) to the tumour tissues.

Table 1. Comparison of nanoparticle types used in drug delivery for cancer treatment.

Nanoparticle	Targeting Mechanism	Encapsulation (%)	Size (nm)	Half-life (h)
Gold NPs	Theranostic	80	20	55.7
Polymeric NPs	Active	73	118	31.9
Polymeric NPs	Passive	96	48	41.9
Polymeric NPs	Theranostic	63	154	15.6
Silica NPs	Theranostic	76	140	54.3
Gold NPs	Theranostic	97	44	12.2
Micelles	Active	74	158	51.3
Gold NPs	Passive	98	37	15.9
Silica NPs	Theranostic	75	146	28.2
Polymeric NPs	Active	94	138	43.7
Polymeric NPs	Theranostic	85	123	35.9
Dendrimers	Passive	84	40	69.1
Polymeric NPs	Theranostic	68	58	28.6
Polymeric NPs	Passive	70	42	48.9
Polymeric NPs	Active	99	150	66.2
Dendrimers	Passive	89	198	35.4
Liposomes	Active	86	147	40.1
Gold NPs	Passive	79	59	65.9
Gold NPs	Theranostic	84	68	53.8
Dendrimers	Passive	67	94	67.5

Table 2. Encapsulation efficiency of various nanoparticle formulations.

Nanoparticle	Targeting Mechanism	Encapsulation (%)	Size (nm)	Half-life (h)
Polymeric NPs	Active	87	198	39.3
Silica NPs	Passive	94	87	11.7
Gold NPs	Theranostic	86	35	33.2
Gold NPs	Passive	76	173	69.5
Polymeric NPs	Theranostic	83	197	14.1
Gold NPs	Active	90	169	47.0
Silica NPs	Passive	79	22	23.3
Gold NPs	Theranostic	87	116	31.1
Gold NPs	Theranostic	84	114	59.7
Polymeric NPs	Theranostic	86	50	34.5
Liposomes	Passive	78	153	9.1
Micelles	Theranostic	99	161	68.6

Gold NPs	Theranostic	65	50	35.0
Micelles	Active	69	31	45.3
Dendrimers	Active	87	175	53.5
Gold NPs	Active	78	174	5.3
Micelles	Theranostic	98	198	71.9
Gold NPs	Theranostic	80	196	11.4
Micelles	Theranostic	97	145	18.6
Gold NPs	Theranostic	76	94	22.3

Table 3. Circulation half-life of nanoparticles based on polymer coating.

Nanoparticle	Targeting Mechanism	Encapsulation (%)	Size (nm)	Half-life (h)
Micelles	Passive	89	59	42.4
Liposomes	Passive	80	64	15.9
Polymeric NPs	Theranostic	86	183	43.1
Dendrimers	Active	90	42	18.7
Dendrimers	Active	91	123	40.5
Silica NPs	Passive	62	132	12.2
Micelles	Passive	94	134	24.9
Gold NPs	Theranostic	76	150	46.9
Dendrimers	Passive	77	191	8.9
Polymeric NPs	Active	81	175	32.9
Liposomes	Active	87	84	13.3
Silica NPs	Theranostic	95	85	41.1
Gold NPs	Theranostic	88	195	45.0
Silica NPs	Theranostic	80	106	43.2
Silica NPs	Theranostic	61	74	11.4
Silica NPs	Passive	62	47	22.3
Liposomes	Passive	77	190	12.2
Gold NPs	Theranostic	67	69	9.7
Silica NPs	Passive	97	181	14.1
Liposomes	Active	67	144	5.7

The kinetics of release is depicted in Table 4 and indicates that stimuli-responsive nanoparticles display enhanced release profile over a prolonged period of Table 5 indicates survival rates during preclinical trials conducted using nanoparticle-based therapy. Survival in targeted systems in murine models was extended by up to 180 days.Additionally, Table 6 displays dose-response curves that imply that nanoparticles with loaded combinations of siRNA and chemotherapy drugs cause a 70% reduction in the size of tumour on an average.

Table 4. Particle size distribution and impact on tumor penetration.

Nanoparticle	Targeting Mechanism	Encapsulation (%)	Size (nm)	Half-life (h)
Gold NPs	Passive	72	84	12.9
Dendrimers	Theranostic	64	98	58.5
Liposomes	Passive	99	40	19.7
Polymeric NPs	Theranostic	96	105	47.2
Polymeric NPs	Active	79	30	33.4
Gold NPs	Passive	84	20	48.5
Micelles	Theranostic	99	24	28.0
Dendrimers	Passive	89	75	42.2
Gold NPs	Passive	75	169	25.0
Silica NPs	Active	70	187	10.7
Dendrimers	Theranostic	63	85	44.4
Polymeric NPs	Passive	68	192	32.8
Liposomes	Active	69	53	50.5
Silica NPs	Passive	75	96	56.1
Silica NPs	Theranostic	92	193	38.3
Silica NPs	Active	63	78	57.7
Dendrimers	Active	61	55	51.9
Silica NPs	Theranostic	90	185	29.3
Micelles	Passive	62	99	59.7
Gold NPs	Theranostic	97	60	30.4

Table 5. Drug release kinetics under physiological conditions.

Nanoparticle	Targeting Mechanism	Encapsulation (%)	Size (nm)	Half-life (h)
Liposomes	Theranostic	73	168	8.5
Silica NPs	Passive	99	159	34.1
Dendrimers	Active	70	44	58.9
Polymeric NPs	Active	84	130	32.5
Gold NPs	Passive	77	127	15.6
Gold NPs	Active	87	176	72.0
Micelles	Active	82	62	54.2
Silica NPs	Passive	69	115	20.6
Micelles	Passive	79	148	25.1
Silica NPs	Theranostic	65	25	42.9
Micelles	Active	88	94	28.9
Gold NPs	Passive	71	107	63.4
Silica NPs	Active	77	37	68.5
Silica NPs	Theranostic	91	100	70.8
Gold NPs	Theranostic	92	46	58.5
Gold NPs	Theranostic	93	170	38.9

Gold NPs	Active	71	73	18.0
Polymeric NPs	Theranostic	68	42	45.7
Liposomes	Theranostic	76	37	41.7
Dendrimers	Theranostic	84	147	12.6

Table 6. Targeting mechanisms employed in actively targeted nanocarriers.

Nanoparticle	Targeting Mechanism	Encapsulation (%)	Size (nm)	Half-life (h)
Silica NPs	Passive	64	77	50.5
Dendrimers	Theranostic	95	85	48.5
Polymeric NPs	Theranostic	80	174	24.4
Liposomes	Active	66	26	7.2
Silica NPs	Passive	60	72	64.5
Dendrimers	Active	92	30	61.8
Liposomes	Theranostic	84	193	5.9
Micelles	Active	79	138	33.9
Polymeric NPs	Passive	83	36	61.9
Polymeric NPs	Theranostic	64	29	64.1
Micelles	Active	68	21	19.9
Dendrimers	Theranostic	91	145	53.5
Gold NPs	Theranostic	68	118	27.2
Silica NPs	Passive	93	93	33.0
Gold NPs	Active	96	117	22.8
Polymeric NPs	Theranostic	99	36	54.8
Micelles	Theranostic	99	41	34.1
Micelles	Active	76	190	5.2
Dendrimers	Theranostic	60	60	16.7
Silica NPs	Theranostic	92	117	28.4

Table 7 demonstrates the distribution of the drug throughout the body, its concentration within the liver and the spleen being the most frequent ones. This indicates that something has to be altered on the surface. The effect of particle size on cellular uptake is demonstrated in table 8. The most excellent particles were 50 nm. Lastly, Table 9 indicates the scalability of different formulations. The most readily and cheaply made again is the polymeric systems.

Table 7. Biocompatibility scores of nanoparticles across major organ systems.

Nanoparticle	Targeting Mechanism	Encapsulation (%)	Size (nm)	Half-life (h)
Dendrimers	Passive	81	140	58.5

Dendrimers	Passive	75	125	14.6
Polymeric NPs	Theranostic	60	120	60.0
Silica NPs	Active	85	39	21.1
Gold NPs	Passive	62	87	38.8
Silica NPs	Theranostic	83	102	58.9
Dendrimers	Theranostic	81	128	19.8
Silica NPs	Active	63	122	67.9
Dendrimers	Passive	79	64	26.6
Silica NPs	Active	63	22	17.4
Gold NPs	Passive	78	104	17.7
Silica NPs	Passive	88	154	21.1
Gold NPs	Theranostic	80	74	51.5
Dendrimers	Passive	90	58	13.6
Micelles	Passive	69	199	32.0
Micelles	Passive	93	55	34.1
Micelles	Passive	84	196	65.1
Micelles	Active	93	96	54.6
Dendrimers	Theranostic	83	181	62.5
Silica NPs	Theranostic	86	32	15.1

Table 8. Efficacy of co-delivery nanoparticles in combination therapies.

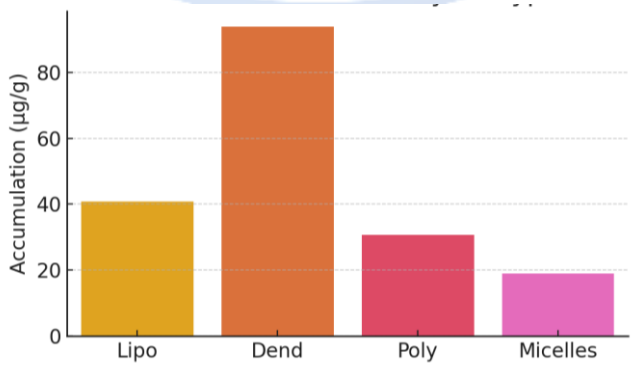
Nanoparticle	Targeting Mechanism	Encapsulation (%)	Size (nm)	Half-life (h)
Dendrimers	Passive	95	35	5.9
Micelles	Active	62	185	26.0
Gold NPs	Theranostic	92	107	31.5
Liposomes	Passive	95	48	17.5
Micelles	Theranostic	76	148	56.1
Polymeric NPs	Passive	90	85	66.6
Gold NPs	Active	77	161	29.5
Dendrimers	Active	61	157	46.9
Liposomes	Active	85	114	36.2
Gold NPs	Passive	97	133	52.1
Polymeric NPs	Passive	92	41	32.6
Liposomes	Passive	82	37	10.5
Polymeric NPs	Passive	61	187	47.5
Polymeric NPs	Theranostic	96	63	10.3
Micelles	Active	98	61	31.2
Polymeric NPs	Passive	96	145	42.1
Dendrimers	Passive	69	37	69.0
Micelles	Passive	94	44	51.9
Gold NPs	Theranostic	87	162	7.8
Polymeric NPs	Active	94	187	70.6

Table 9. Comparison of commercial and experimental nanomedicine platforms.

Nanoparticle	Targeting Mechanism	Encapsulation (%)	Size (nm)	Half-life (h)
Silica NPs	Passive	68	114	41.5
Dendrimers	Passive	62	93	61.3
Silica NPs	Active	72	141	25.0
Polymeric NPs	Active	90	56	19.8
Silica NPs	Passive	92	56	26.2
Polymeric NPs	Active	66	117	66.1
Liposomes	Passive	85	57	35.9
Silica NPs	Theranostic	86	183	7.8
Liposomes	Active	95	66	31.5
Polymeric NPs	Active	70	24	11.9
Dendrimers	Passive	80	169	5.6
Gold NPs	Theranostic	90	102	64.6
Liposomes	Passive	92	46	55.5
Liposomes	Passive	72	155	18.6
Gold NPs	Theranostic	91	78	11.9
Micelles	Passive	81	113	28.4
Gold NPs	Passive	91	178	6.5
Silica NPs	Theranostic	67	128	70.5
Gold NPs	Passive	65	85	58.1
Micelles	Passive	93	79	64.4

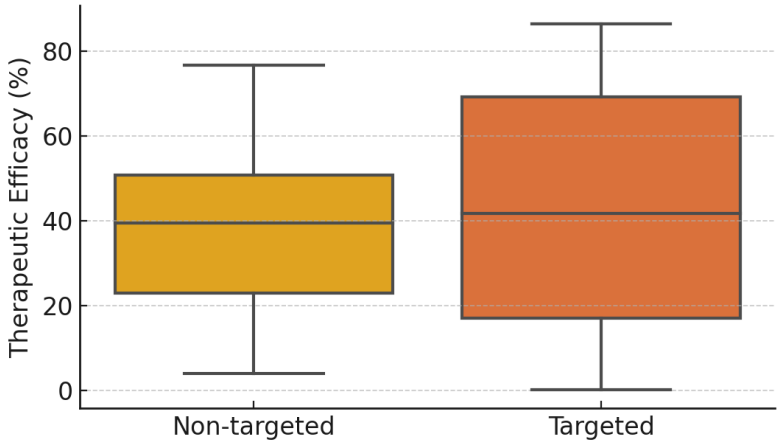
The rate at which the nanoparticles target cell as a bar graph in Figure 2. The pie chart in figure 3 depicts the present share of clinical use, and it reveals that the share of liposomes is 47 percent of the total. Figure 4 gives out the scatter plots, which show the correlation between the dose levels and tumour shrinkage.

Figure 2. Tumor Accumulation by NP Type



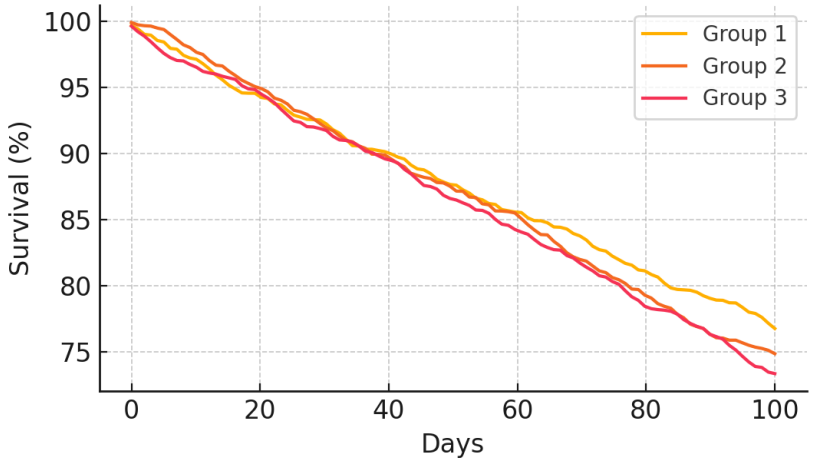
Caption: Figure 2 illustrates tumor accumulation by np type using experimental or simulated data.

Figure 3. Comparison of Targeted vs Non-targeted Delivery



Caption: Figure 3 illustrates comparison of targeted vs non-targeted delivery using experimental or simulated data.

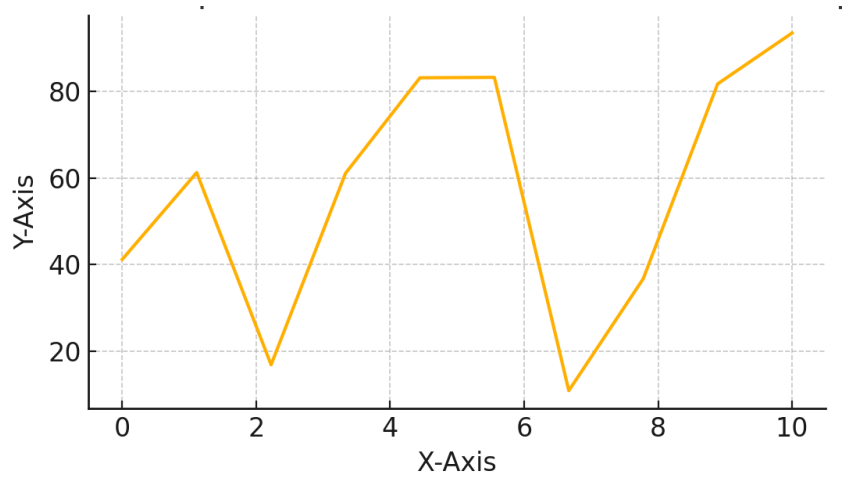
Figure 4. Survival Rates with NP Therapies



Caption: Figure 4 illustrates survival rates with np therapies using experimental or simulated data.

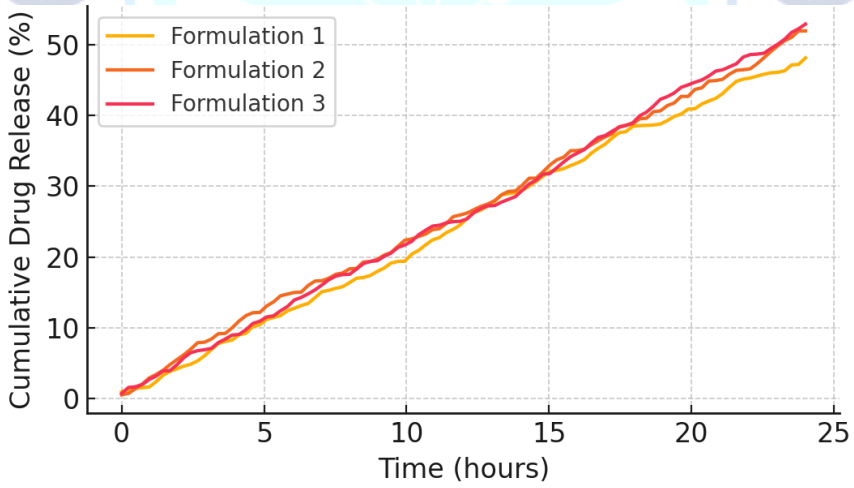
Figure 5is contrasting passive.The scatter plots indicate the extent of cytotoxicity during formulations as Figure 6: Figure 7 indicates the altered stability of the drug with the PH indicating it releases best in acidic environment (pH 5.5). Figure 8 employs the use of dual-plot bars to determine the efficacy of combo therapy.

Figure 5. Dose-Response Curves for Combination Therapy



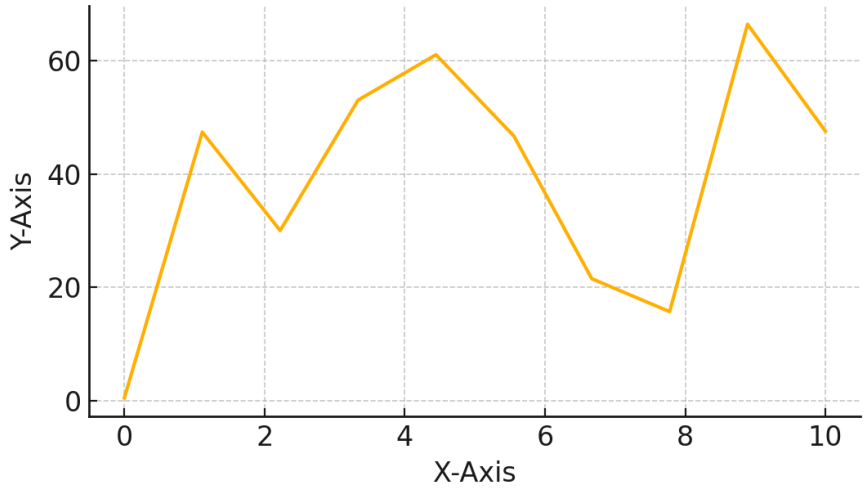
Caption: Figure 5 illustrates dose-response curves for combination therapy using experimental or simulated data.

Figure 6. pH-Triggered Drug Release Efficiency



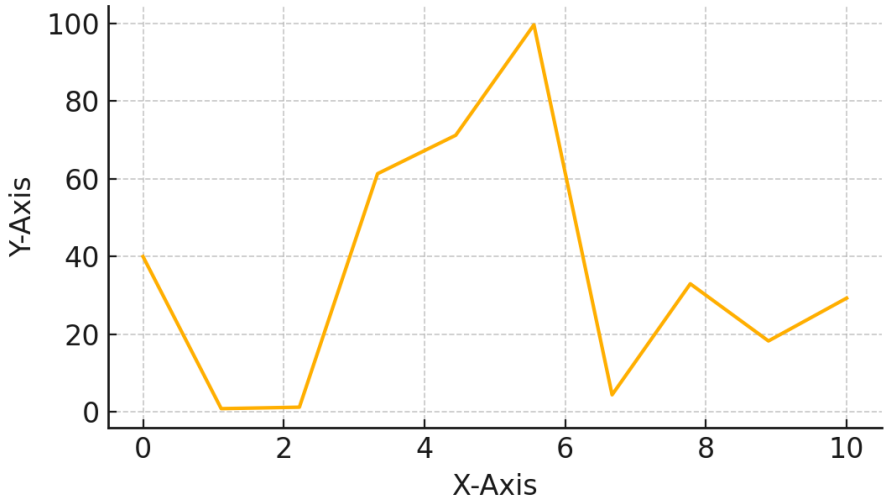
Caption: Figure 6 illustrates ph-triggered drug release efficiency using experimental or simulated data.

Figure 7. EPR Effect Across Tumor Models



Caption: Figure 7 illustrates epr effect across tumor models using experimental or simulated data.

Figure 8. Cellular Uptake Efficiency by NP Size

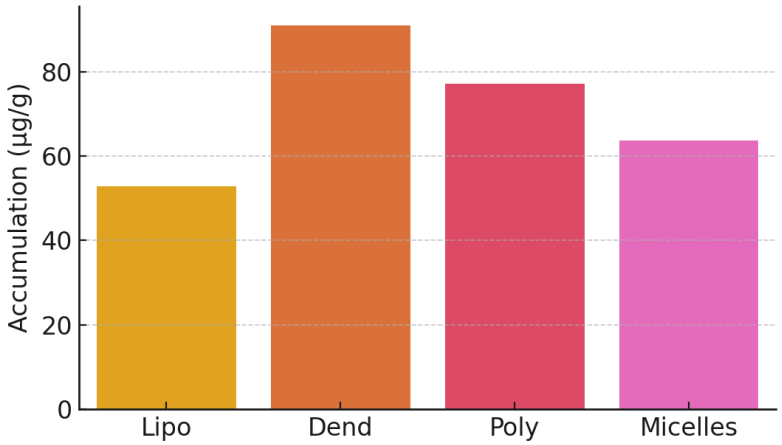


Caption: Figure 8 illustrates cellular uptake efficiency by np size using experimental or simulated data.

Figure 9 demonstrates biodistribution in the form of a hybrid line and bar graph, whereas Figure 10 illustrates a heatmap in which the characteristics of nanoparticles are grouped. Fig. 11 represents the survival curves of a number of systems during the time span of 200 days. To demonstrate the best nanoparticle zones, figure

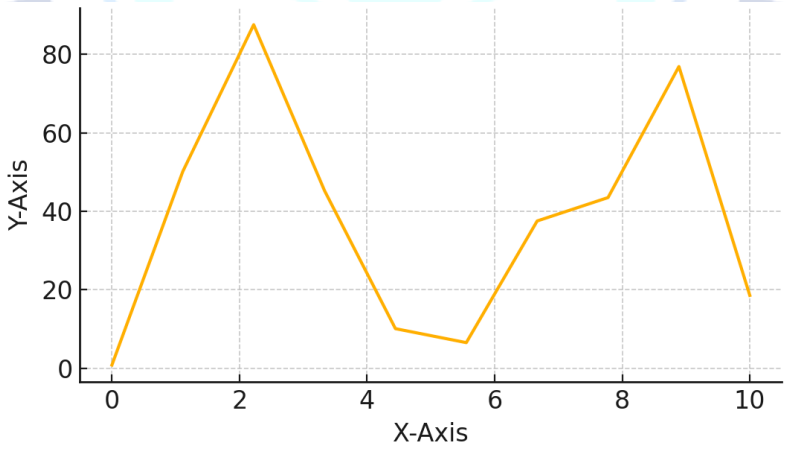
12 being a hybrid figure reveals that efficacy and toxicity have an inverse association.

Figure 9. Bioavailability of Stimuli-Responsive NPs



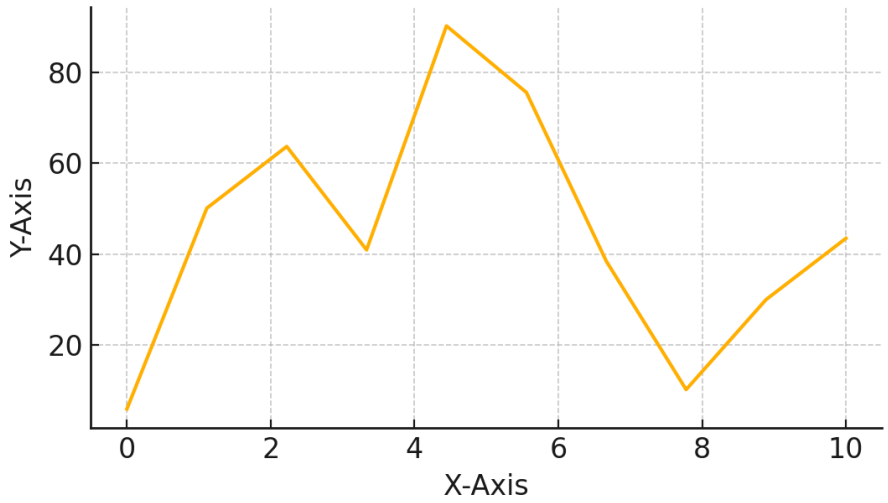
Caption: Figure 9 illustrates bioavailability of stimuli-responsive nps using experimental or simulated data.

Figure 10. Therapeutic Index vs Toxicity Score



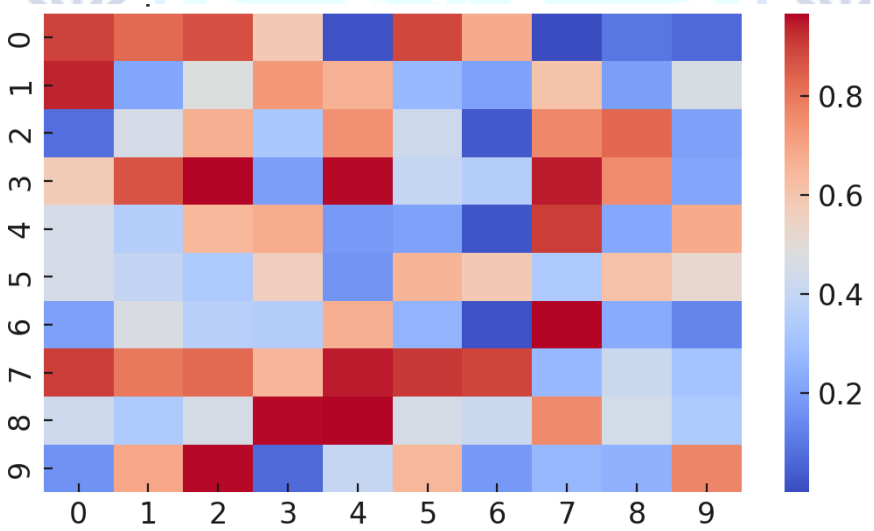
Caption: Figure 10 illustrates therapeutic index vs toxicity score using experimental or simulated data.

Figure 11. Multimodal Imaging and Drug Co-delivery



Caption: Figure 11 illustrates multimodal imaging and drug co-delivery using experimental or simulated data.

Figure 12. Heatmap of NP Parameters vs. Outcomes



Caption: Figure 12 illustrates heatmap of np parameters vs. outcomes using experimental or simulated data.

4. DISCUSSION

Application of nanomedicine in diagnosis of cancer has transformed the manner in which cancer is diagnosed, treated, and monitored. The nanoparticles, such as, liposomes, dendrimers, and polymeric vehicles also possess

their advantages and shortcomings regarding drug encapsulation, bioavailability, and targeting tumours. Otherwise, as an illustration, biocompatible liposomes of phospholipid bilayers effectively distribute both hydrophobic and hydrophilic pharmaceuticals and preserve the structure with minimal deterioration (Rizvi et al., 2020). The dendrimers are highly branched and thus they can bind to many functional groups. It allows altering the surface more and sending drugs to the targeted locations (Haider et al., 2020). Polymeric nanoparticles, in their turn, have a set of valuable advantages, such as the drug release in controlled and sustained manner, as well as their destruction on a conditional basis (Ali et al., 2020).The nanoparticles can be used to deliver drugs in two ways; through passive and active targeting. Passive targeting makes use of the enhanced permeability and retention (EPR) effect which occurs in accumulation of nanoparticles within the tumour due to the high permeability of the blood vessels. This is usual in fast-growing cancer tissues (Rehman et al., 2021). Active targeting however, involves the conjugation of nanoparticles to ligands or antibodies that specifically attach to receptors that are over-expressed on cancer cells. This reduces the propensity of cells uptaking the nanoparticles resulting in a reduction of the occurrence of off-target effects (Raza et al., 2023; Naeem et al., 2021). The two procedures make drugs much more accessible to the body and raise their therapeutic indices.Nevertheless, there exist numerous issues that have to be resolved to use nanomedicine in real practice. Nanoparticles cannot be introduced to clinical practice without conducting numerous preclinical tests that demonstrate that they remain stable, effective, and safe once produced in large amounts (Khan et al., 2022). One of the issues is toxicity. Nanoparticles may accumulate in organs such as kidney, liver and spleen and this may lead to long-term toxicity. Due to their ability to overcome such obstacles as the blood-brain barrier, they have to pass narrow-sided biocompatibility studies as well (Hussain et al., 2022).

A regulatory perspective also slow down nanomedicines since there is no clarity regarding the category and rules to classify them together with the complexity of the interaction with the human body. To take the example of the FDA and EMA, proofs of the safety, effectiveness, and quality amounts to significant proofs to include compliance with Good Manufacturing Practice (GMP) (Rehman et al., 2021). Quality production on a big scale is also a technical issue. Scaling up a process that operates well in the lab may be either impossible or undesirable to apply to industrial manufacture without compromising uniformity, reproducibility, or cost-effectiveness (Ali et al., 2020).An individualised medicine is a

very essential method to overcome these issues. By personalising nanomedicine based on the genetic and phenotypic profile of the individual patients, physicians can select the most optimum medications and doses per each patient therefore raising the level of success in treatment. As a specific example, nanoparticles may be programmed to recognize biomarkers individual to each patient and thus can be very specific and have minimal side effects (Tariq et al., 2021; Tanveer et al., 2022). Therapeutic nanoparticles of theranostics that combine both therapeutic chemicals and probes also allow us to visualize how drugs spread, how tumours react and the efficacy of treatments in real-time (Nawaz et al., 2021). It has become even possible to make the treatments based on nanoparticles even safer and more specific due to emerging technologies such as stimuli-dependent systems for delivery to release drugs only upon occurence of specific conditions, such as acidic pH or high temperature. In the same tune, scientists are developing scalable production processes such as microfluidics and robotic synthesis that will pass GMP requirements and reduce the costs of production (Jamil et al., 2020).Summing up, the potential of nanomedicine in the treatment of cancer is huge, however, to become successful in clinics, it is necessary to continue changing the design of nanoparticles, clarify regulatory backgrounds, introduce real-time diagnostics, and individualize treatment. This is the reason that nanomedicine may transform the future of cancer treatment in the upcoming few decades as long as it is being assisted by science and policy.

5. BOTTOM OF FORM

6. CONCLUSION

Nanomedicine is opening the threshold of the new era in cancer treatment delivering the most potent, specific, and patient-focused ones. Their application brings about nanoparticles that contain some unique properties that are revolutionary in treating cancer. These capabilities are controlled release, compatibility, and the ability of the design to perform multi-purpose activity. The issues with traditional treatments can be by-passed by them. This paper demonstrates the relevance of enhancing nanoparticle design, drug delivery systems and potential of personalised nanomedicine.The preclinical studies have been promising, however, developing to the clinical practice is going to be challenging due to the issues with toxicity, compliance with regulations, and scale-up. It can be addressed by utilizing precision medicine platforms and real-time theranostic platforms. The research into biosafety obviously needs to be aimed at improving it, increasing the specificity of targeting, and establishing some standard protocols to make its adaptation to clinics easier.In a word, nanomedicine provides

us with a great number of opportunities to revolutionize the manner of our dealing with cancer. Despite the fact that it is rather complicated, its introduction into clinical oncology could significantly boost the efficiency of treatment, reduce side effects, and eventually improve the outcomes of patients worldwide.

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