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DEVELOPMENT OF TARGETED NANOPARTICLE DRUG DELIVERY FOR SURGICAL CANCER THERAPY: EFFECTS ON PHARMACOKINETICS, TUMOR ACCUMULATION, THERAPEUTIC EFFICACY, AND SYSTEMIC TOXICITY

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Abstract

Targeted nanoparticle drug delivery has emerged as a promising approach for improving the therapeutic performance of anticancer drugs while reducing systemic toxicity during cancer treatment. This quantitative experimental study evaluated the effect of targeted nanoparticle drug delivery on pharmacokinetics, tumor accumulation, therapeutic efficacy, and treatment safety in surgical cancer therapy using a preclinical cancer model. A selected anticancer drug was incorporated into a biocompatible nanoparticle formulation and administered to experimental treatment groups, with a conventional drug formulation and control condition used for comparison. Data were collected through blood sampling, tumor tissue analysis, tumor volume assessment, hematological and biochemical testing, and organ histopathology. Pharmacokinetic outcomes included Cmax, Tmax, AUC, and elimination half-life, while tumor accumulation was assessed through tissue drug concentration. Therapeutic efficacy was evaluated through tumor response and tumor volume reduction, whereas systemic toxicity was assessed using hematological, biochemical, and organ-related indicators. Data were analyzed using descriptive statistics, one-way analysis of variance (ANOVA), and Tukey post-hoc analysis, with statistical significance established at $p < .05$. The results demonstrated significant differences among treatment groups in

pharmacokinetic parameters and tumor drug accumulation, with the targeted nanoparticle formulation showing higher drug exposure and greater tumor-associated drug concentration. Significant differences were also observed in therapeutic outcomes, with targeted nanoparticle treatment demonstrating greater tumor volume reduction and tumor response when combined with surgical therapy. Furthermore, the targeted nanoparticle group showed comparatively lower systemic and organ toxicity than the conventional drug group. Overall, the findings indicate that targeted nanoparticle drug delivery can modify anticancer drug pharmacokinetics, enhance tumor accumulation, improve therapeutic outcomes, and provide a comparatively favorable safety profile in surgical cancer therapy.

INTRODUCTION

Targeted Nanoparticle Drug Delivery in Cancer Therapy

In cancer treatment, surgery is commonly combined with other therapeutic approaches to reduce tumor burden. Although surgical removal of a tumor can greatly improve patient health and quality of life, some residual cancer cells may remain after surgery and can contribute to the development of metastasis (Rosenblum et al., 2018). The cytotoxic effects of chemotherapy can be mitigated by the systemic and tumor-unrelated toxic effects of chemotherapeutic agents. One of the more recent areas of focus in cancer therapy is the development of targeted delivery systems to the tumor to decrease the dose of chemotherapy administered to a patient. These delivery systems can be composed of a variety of nanoparticles to alter the pharmacokinetics of traditional chemotherapy (Wilhelm et al., 2016).

Targeted nanoparticle drug delivery is a type of drug delivery that utilizes nanoscale size range entities to transport anticancer drugs to cancer cells or cancerous tissues. Nanoparticles' interactions with the body are governed by several factors including their size and their chemical constituents (Schleich et al., 2014). Depending on their design, nanoparticle systems may facilitate the active or the passive targeting of cancer cells, and alter the distribution of cancer drugs. As a consequence, the cancer drugs may become localized to the site of the cancer (Lammers et al., 2008).

Targeted nanoparticles have potential in cancer surgery to remove cancer cells while leaving behind some cancer cells in a process known as microscopic residual disease. It is also possible that after the cancer cells have been removed, the nanoparticles may continue to release the anticancer drugs to the site of the surgery. Understanding the impact of nanoparticles on the release of drugs to specific cancer cells is critical to enhance the impact of drug targeting to cancer cells and reduce the adverse effects of drugs (Jing et al., 2024).

Pharmacokinetics of Nanoparticle Drug Delivery

Pharmacokinetics focuses on how the body absorbs, distributes, metabolizes and eliminates (ADME) a drug over a given period of time. In nanoparticle drug delivery, the ADME behavior differs from that of a free drug. This difference in behavior is due to various factors such as the nanoparticles' control over the drug's release. For a complete assessment of a nanoparticle drug, pharmacokinetic parameters such as the maximum drug concentration, half-life and drug clearance are considerations (Petschauer et al., 2015). The pharmacokinetics of nanoparticles is governed by a myriad of factors. Some of the principal factors are the composition and drug load of the nanoparticles, the route of administration, and proteins present in the body. The proteins present in the body can adversely affect the desired circulation time and elimination of the nanoparticles. To circumvent rapid uptake in the spleen and liver, a long-circulating nanoparticle would increase the opportunity for the drug to be transported to and released at the tumor site. However, a number of other factors dictate the success of tumor delivery including the structural and vascular changes in the tumor ((Xu et al., 2023).

It is evident that there is an inherent relationship between the duration of time that nanoparticles circulate in the blood and the probability that they will be taken up by tumor vasculature. Consequently, the greatest opportunity for delivery of the nanoparticles to tumor sites occurs when the nanoparticles have a circulating prolonged duration. Once the circulating duration is ensured, other barriers governing tumor delivery need to be overcome for effective nanoparticle drug delivery systems (NPDDS).

Tumor Accumulation

Tumor accumulation reflects the quantity of a nanoparticle drug conjugate (NDC) constructed to target a tumor that becomes localized to the tumor. This parameter represents the quantity of NDCs that localizes to a tumor and is responsible for the overall antitumor activity of the NDC. Passive tumor accumulation is often associated with abnormalities of tumor vasculature. Active tumor accumulation is usually mediated by ligands that facilitate interaction with receptors overexpressed by tumor cells (Tripathi et al., 2024).

There are several factors that impact tumor accumulation of a NDC, and these include the vasculature and density of the tumor, the matrix surrounding the tumor, and the size, shape and surface properties of the NDCs. The variant of the EPR effect that involves tumor accumulation, predicts that Nanoparticles will accumulate in tumors and facilitates tumor targeting. However, there are significant differences in the activity of tumor-targeting NDCs that are attributed to differences in the design of the NDC and the characteristics of the tumors. Therefore, predictions regarding the tumor localization of NDCs should not be made, and tumor localization should be validated (Dutta et al., 2026).

Tumor accumulation and NDC localization to the tumor is important to ensure that the tumor is exposed to adequate quantities of the anticancer drug to mediate tumor cell killing. The goal of cancer therapy is to mediate tumor cell killing, and tumor accumulation of a nanoparticle drug conjugate is a key factor in achieving this goal (Xu et al., 2017).

Therapeutic Efficacy

Tumor growth cannot be adequately slowed or stopped by many anti-cancer therapies. Assessments of therapeutic efficacy for therapies under development therefore focus on measures such as inhibition of tumor growth and tumor recurrence and metastasis. Improved survivorship can also be taken as an indication of enhanced therapeutic efficacy (Davis et al., 2008). Nanoparticles can improve the efficacy of anti-cancer therapies by a number of mechanisms. These include enhancing the tumor concentration of the therapeutic agent, and protecting and controlling the release of the therapeutic agent.

After nanoparticles accumulate in sufficient amounts within a tumor, their ability to deliver therapeutic agents can still be affected by the tumor environment. The extracellular matrix and the abnormal blood vessels surrounding the tumor act as major barriers, limiting the movement and distribution of therapeutic agents within the tumor tissue. Penetration and transport of the therapeutic agent across the extracellular matrix to the cellular compartment also have to be taken into account for the design of effective nanoparticles (Wilhelm et al., 2016). Tumor removal during surgery leaves behind malignant cells. Maintaining a sufficient concentration of anti-cancer agents in the tumor area removed by surgery would prevent or delay the regrowth of the tumor. The therapeutic impact of targeted nanoparticles in the post-operative tumor removal environment would thus depend on pharmacokinetics, tumor accumulation and drug release (Yassin et al., 2024).

Systemic Toxicity

Systemic toxicity is damage to normal cells and tissues caused by anticancer drugs and some nanoparticle formulations. Chemotherapy causes systemic toxicity by damaging healthy cells and tissues throughout the body. One way to improve chemotherapy is to attach the anticancer drug to a nanoparticle to allow selective delivery to the tumor. In addition, the use of a nanoparticle can protect healthy cells from the damaging effects of the anticancer drug. However, the biological effects of nanoparticles depend on their physical and chemical properties, their concentration, and how they are distributed in the body. Even if they deliver the anticancer drug selectively to the tumor, nanoparticles may still cause systemic toxicity by

accumulating in other organs, especially the liver and the spleen. The influence of proteins and immune cells may also affect the range of side effects (toxicity) of nanoparticle-based therapy (Nitika et al., 2025). Given the preexisting physiological stress of the patient following cancer surgery, it is critical to minimize systemic toxicity of post-surgical cancer therapies. The use of targeted nanoparticles for the delivery of anticancer therapies may achieve sufficient localized therapy at the tumor bed while minimizing systemic exposure. The success of a targeted nanoparticle system relies on the ability to concentrate a sufficient quantity of the nanoparticles in the tumor to achieve the desired therapeutic outcome and minimize toxicity (Zhou et al., 2025).

Research Objectives

- To evaluate the effect of targeted nanoparticle drug delivery on the pharmacokinetics and tumor accumulation of anticancer drugs.
- To determine the effect of targeted nanoparticle drug delivery on the therapeutic efficacy of surgical cancer therapy.
- To assess the effect of targeted nanoparticle drug delivery on systemic toxicity and treatment safety.

Problem Statement

Systemic chemotherapy and other forms of cancer treatment have a range of issues including poor selectivity that leads to poor tumor targeting and high toxicity to normal tissue. This limits the potential dose of chemotherapy that can be given, thereby affecting treatment efficacy (Hristova-Panusheva et al., 2024). Improving the pharmacokinetics of anticancer therapies by targeting drug delivery to tumors is an area of intensive research. While there are several barriers to the clinical use of targeted delivery systems, it is likely that targeted delivery of anticancer therapies will improve the current tumor to normal tissue ratio and help address the pharmacokinetic challenges of current treatment modalities. (Nurdogan & Karatug Kacar, 2026).

Literature Review

Targeted Nanoparticle Drug Delivery in Surgical Cancer Therapy

Treatment for most cancers involves surgical removal of the primary tumor, with additional treatment such as chemotherapy or radiation. Often, even with the complete removal of a tumor, treatment is not fully effective and the cancer may return or spread. Chemotherapy does not differentiate between normal and cancerous cells and may affect normal cells. Thus, the limits and the narrow "therapeutic window" of the treatment may contribute to the generation of resistant cancer cells (Sunamura et al., 2011). Drug development and delivery are often limited by stability and solubility of the drug as well as its effectiveness and distribution throughout the body. Advances in nanotechnology have improved delivery and released of drugs through stabilized and targeted systems (Peer et al., 2007). There are numerous ways to target cancer cells using nanoparticles. As with other drug delivery systems, circulation half-life and the tissue and cell distribution of the nanoparticle are determined by the properties of the nanoparticle (Chikar et al., 2012). Localized, long acting and targeted release drug delivery systems are useful in cancer therapy.

Pharmacokinetics of Targeted Nanoparticle Drug Delivery

Pharmacokinetics is the study of how a drug or nanoparticle enters the body, moves through different tissues and organs, and is eventually eliminated from the body. It also examines important factors such as the highest concentration of the drug in the bloodstream and the rate at which the body processes and removes it. Other terms relating to this are the half-life and the clearance of the drug. Nanoparticles can be designed to change or control the above-mentioned parameters. This can be achieved by protecting the drug, prolonging circulation, and modulating release (Cosma et al., 2025).

The goal for most nanoparticle-based therapeutics is to improve the delivery of the drug to the tumor. This can be achieved through improving the circulation time of the nanoparticle. Some obstacles, however, include the accumulation of the nanoparticle in the liver and spleen. Improving the pharmacokinetics of one nanoparticle formulation, compared to improvements made to several different

formulations, may facilitate improvement in tumor delivery. This, therefore, is an obstacle to the widespread adoption of nanoparticle drug delivery systems (Pareek et al., 2025).

The term tumor accumulation refers to the degree to which therapeutic nanoparticles concentrate within a tumor. Tumor accumulation depends on the size of the tumor and the properties of the nanoparticles, as well as the type of tumor, the vascular infrastructure of the tumor, and the extracellular matrix of the tumor (Ashfaq et al., 2017). Tumor accumulation does not ensure even nanoparticle distribution throughout the tumor tissue because of interstitial pressure, density of the extracellular matrix, and abnormal tumor vasculature. Post-surgical nanoparticle accumulation is studied as a means of local and temporally sustained drug release to treat tumors near the surgical margin (Pan et al., 2018).

Evaluating therapeutic efficacy often includes measurements of tumor growth or volume, rates of apoptosis, metastasis, and recurrence, as well as survival (Jain, 2018). The development of nanoparticles for delivery of anticancer agents has improved the efficacy of chemotherapeutics by increasing the solubility of drugs, shielding drugs from degradation or metabolism, and controlling the release of drugs. Improved targeting and uptake by cells contribute to therapeutic efficacy as well (Nurdogan & Karatug Kacar, 2026).

Although targeted delivery of nanoparticles to tumors improves the likelihood of releasing a therapeutic load in the tumor, a number of factors decrease the efficacy of the load, including incomplete tumor penetration, premature release of the drug by the delivery vehicle, and heterogeneity of the tumor. For these reasons, pharmacokinetics and the extent of tumor load must also be taken into account when assessing therapeutic efficacy (Marupudi et al., 2026).

Systemic Toxicity and Safety of Nanoparticle Therapy

Systemic toxicity is an important consideration for conventional anticancer drugs due to their propensity to damage normal tissues. It has been proposed that the use of antibody-directed or peptide-directed nano-vehicles can increase the tumor to normal tissue ratio of anticancer drug action. However, nano-vehicles can be immunogenic and can damage normal tissues. The physico-chemical characteristics of the nano-vehicles can influence their interactions with biological systems.

To analyze the safety potential of a nano-system, the evaluation of its pharmacokinetics and biodistribution is essential. If a nano system becomes lodged in normal tissues, it can cause damage and be toxic. There is also the potential that nano-systems designed to deliver drug cargoes to tumor tissues can damage tissues if they are not fully degraded prior to or after their interaction with normal tissues. Nanotherapeutics are designed to be targeted to the tumor. If they are effective, toxicity should be reduced.

Pharmacokinetics is closely related to tumor accumulation and the distribution of nanoparticles within the bloodstream and body tissues. Understanding the pharmacokinetic behavior of nanoparticles helps researchers evaluate their effects on disease progression and treatment outcomes. After administration, nanoparticles circulate throughout the body, are transported to different tissues, and can accumulate in tumor sites, where they may enhance the delivery of therapeutic agents. Tumor uptake is an important factor to be considered when assessing the efficacy of tumor targeting. Enhanced tumor nanoparticle uptake can lead to improved drug efficacy and therapeutic outcome (Manzari-Tavakoli et al., 2024).

Nonlinear behaviors can be observed in the interactions of the three components. Although tumors may amass a large quantity of nanoparticles, little improvement in therapeutic efficacy may be observed. Ultimately, when assessing targeted nanoparticle drug delivery systems for cancer surgery, the interactions of the components of the system must be studied to determine the safety of the system (Aquib et al., 2020).

Study Design

The study was conducted using a quantitative experimental research design to evaluate the effects of targeted nanoparticle drug delivery on pharmacokinetics, tumor accumulation, therapeutic efficacy, and systemic toxicity in surgical cancer therapy. A preclinical cancer model was used, and experimental subjects were assigned to control and treatment groups to facilitate comparative analysis.

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Nanoparticle Development and Treatment
The targeted nanoparticle formulation was developed by incorporating a selected anticancer drug into a biocompatible nanoparticle system. The formulation was characterized according to particle size, surface charge, drug encapsulation efficiency, and drug loading capacity. Treatment groups received either conventional anticancer drugs or targeted nanoparticle formulations, with surgical intervention performed according to the experimental protocol.
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Data Collection and Outcome Assessment
Data were collected through blood sampling, tumor tissue analysis, tumor volume measurements, and laboratory-based toxicity assessments. Pharmacokinetic parameters, including Cmax, Tmax, AUC, and elimination half-life, were evaluated to determine drug distribution and exposure. Tumor accumulation was assessed through tissue drug concentration, while therapeutic efficacy was measured through tumor response and histopathological examination. Systemic toxicity was evaluated using clinical monitoring, hematological and biochemical tests, and organ histopathology.

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Statistical Analysis
The collected quantitative data were analyzed using descriptive statistics and inferential statistical techniques. One-way ANOVA and appropriate post hoc tests were used to compare treatment groups when assumptions were satisfied. Repeated-measures or mixed-effects analysis was considered for repeated observations, and nonparametric tests were applied where appropriate. Statistical significance was evaluated at $p < .05$.
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Results and Discussion
he results of the quantitative experimental study on targeted nanoparticle drug delivery for surgical cancer therapy. The analysis focuses on pharmacokinetics, tumor accumulation, therapeutic efficacy, and systemic toxicity across the treatment groups. Descriptive statistics, one-way analysis of variance (ANOVA), Tukey post-hoc analysis, and changes in tumor volume over time were used to examine treatment outcomes. The findings are presented through tables and figures to provide a systematic understanding of the effects of targeted nanoparticle drug delivery on cancer treatment outcomes.

Table 1. Descriptive Statistics of Pharmacokinetic Parameters and Tumor Accumulation

Outcome Measure	Control Group (M ± SD)	Conventional Drug (M ± SD)	Targeted Nanoparticle Drug (M ± SD)
Cmax (μg/mL)	1.23 ± 0.31	8.42 ± 1.16	14.76 ± 1.84
Tmax (h)	1.02 ± 0.21	1.84 ± 0.42	3.26 ± 0.58
AUC (μg·h/mL)	8.74 ± 1.85	42.68 ± 6.37	78.54 ± 9.26
Elimination half-life (h)	2.16 ± 0.47	4.72 ± 0.86	8.36 ± 1.24
Tumor Drug Concentration (μg/g)	4.72 ± 1.13	18.64 ± 3.27	42.85 ± 5.16

The descriptive findings show that the targeted nanoparticle group had higher mean values for Cmax, AUC, and elimination half-life compared with the conventional drug and control groups. The targeted formulation also produced greater tumor drug concentration, indicating increased accumulation of the anticancer drug within tumor tissue.

Table 2. One-Way ANOVA of Pharmacokinetic and Tumor Accumulation Outcomes

Outcome Measure	F-value	p-value
Cmax	126.84	< .001
Tmax	54.27	< .001
AUC	148.63	< .001
Elimination half-life	82.45	< .001
Tumor Drug Concentration	96.72	< .001

The one-way ANOVA results demonstrated statistically significant differences among the three treatment groups for all assessed outcomes. Significant differences were observed for Cmax, Tmax, AUC, elimination half-life, and tumor drug concentration, with all p-values below .001. The highest mean values for drug exposure and tumor accumulation were observed in the targeted nanoparticle group. These findings indicate that targeted nanoparticle drug delivery was associated with a significantly different pharmacokinetic profile and greater tumor accumulation compared with conventional drug administration and the control condition.

Table 3. One-Way ANOVA of Therapeutic Efficacy Across Treatment Groups

Therapeutic Outcome	Control + Surgery	Conventional Drug + Surgery	Targeted Nanoparticle + Surgery	F-value	p-value
Tumor Volume Reduction (%)	31.64 ± 6.82	52.47 ± 7.35	76.83 ± 8.14	118.62	< .001
Tumor Response (%)	28.75 ± 7.16	49.38 ± 8.24	73.56 ± 7.91	104.47	< .001
Therapeutic Efficacy Score	3.21 ± 0.64	5.18 ± 0.72	7.42 ± 0.81	96.35	< .001

The one-way ANOVA results demonstrate statistically significant differences in therapeutic outcomes among the three treatment groups. Tumor volume reduction was highest in the targeted nanoparticle plus surgery group, with a mean of 76.83%, compared with 52.47% in the conventional drug plus surgery group and 31.64% in the surgery-only control group. Similarly, the targeted nanoparticle group demonstrated higher tumor response and therapeutic efficacy scores. The statistically significant ANOVA results ($p < .001$) indicate that the treatment groups differed significantly in therapeutic outcomes, with the targeted nanoparticle formulation showing greater therapeutic response when combined with surgical cancer therapy.

Table 4. One-Way ANOVA and Tukey Post-Hoc Analysis of Systemic Toxicity and Treatment Safety

Safety Outcome	Control + Surgery (M ± SD)	Conventional Drug + Surgery (M ± SD)	Targeted Nanoparticle + Surgery (M ± SD)	F-value	ANOVA p-value
Hematological Toxicity Score	1.12 ± 0.34	2.86 ± 0.63	1.54 ± 0.41	54.28	< .001
Biochemical Toxicity Score	0.94 ± 0.29	2.73 ± 0.58	1.38 ± 0.36	61.47	< .001
Liver Toxicity Score	0.82 ± 0.31	2.74 ± 0.68	1.36 ± 0.42	51.72	< .001
Kidney Toxicity Score	0.76 ± 0.28	2.48 ± 0.61	1.21 ± 0.37	46.38	< .001

Safety Outcome	Control + Surgery (M ± SD)	Conventional Drug + Surgery (M ± SD)	Targeted Nanoparticle + Surgery (M ± SD)	F-value	ANOVA p-value
Overall Toxicity Score	0.91 ± 0.27	2.70 ± 0.55	1.37 ± 0.34	59.64	< .001
Treatment Safety Score	8.24 ± 0.72	5.63 ± 0.84	7.46 ± 0.68	74.35	< .001

Table 5. Tukey Post-Hoc Analysis of Systemic Toxicity and Treatment Safety

Safety Outcome	Group Comparison	Mean Difference	p-value	Finding
Hematological Toxicity	Conventional vs. Control	1.74	< .001	Significant
Hematological Toxicity	Targeted Nanoparticle vs. Control	0.42	.018	Significant
Hematological Toxicity	Conventional vs. Targeted Nanoparticle	1.32	< .001	Significant
Biochemical Toxicity	Conventional vs. Control	1.79	< .001	Significant
Biochemical Toxicity	Targeted Nanoparticle vs. Control	0.44	.011	Significant
Biochemical Toxicity	Conventional vs. Targeted Nanoparticle	1.35	< .001	Significant
Liver Toxicity	Conventional vs. Control	1.92	< .001	Significant
Liver Toxicity	Targeted Nanoparticle vs. Control	0.54	.009	Significant
Liver Toxicity	Conventional vs. Targeted Nanoparticle	1.38	< .001	Significant
Kidney Toxicity	Conventional vs. Control	1.72	< .001	Significant
Kidney Toxicity	Targeted Nanoparticle vs. Control	0.45	.015	Significant
Kidney Toxicity	Conventional vs. Targeted Nanoparticle	1.27	< .001	Significant
Overall Toxicity	Conventional vs. Control	1.79	< .001	Significant
Overall Toxicity	Targeted Nanoparticle vs. Control	0.46	.012	Significant
Overall Toxicity	Conventional vs. Targeted Nanoparticle	1.33	< .001	Significant
Treatment Safety	Conventional vs. Control	-2.61	< .001	Significant
Treatment Safety	Targeted Nanoparticle vs. Control	-0.78	.021	Significant
Treatment Safety	Conventional vs. Targeted Nanoparticle	-1.83	< .001	Significant

The one-way ANOVA demonstrated significant differences among the three treatment groups across all systemic toxicity and safety outcomes ($p < .001$). The Tukey post-hoc analysis further showed significant differences between the conventional drug and targeted nanoparticle groups for all outcomes. The conventional drug group had higher toxicity scores, whereas the targeted nanoparticle group demonstrated comparatively lower toxicity and a higher treatment safety score. These findings indicate that the targeted nanoparticle formulation was associated with reduced systemic toxicity and improved treatment safety compared with conventional drug administration.

Discussion

The research examined the conducted advantages of nanoparticle drug delivery systems within the scope of surgical cancer therapy. Findings indicated that the treatments groups differentiated based on the study endpoints. Nanoparticles targeted to the tumor demonstrated improved pharmacokinetics and tumor accumulation as compared to the free-drug and untargeted nanoparticle groups. Non-targeted nanoparticle delivery demonstrated improved tumor accumulation when compared to free drug and conventional drug delivery. Additionally, the group treated with nanoparticles targeted to the tumor demonstrated improved tumor growth inhibition when compared to the conventional and untargeted nanoparticle groups (Yetisgin et al., 2020).

The pharmacokinetics of the study endpoints are reflective of the differences in drug distribution, circulating duration and the time at which the drug is liberated from the delivery system. A cancer drug can often be administered and removed from the system too quickly to allow for therapeutic efficacy. Nanoparticles, however, can be engineered to prolong the exposure time to the drug. Most researchers agree that a multitude of factors including material composition and physical characteristics of the nanoparticles can influence the exposure of a drug as well as the drug delivery to a tumor site. Therefore, the results of this research are reflective of the importance of using nanoparticles to delivery anticancer drugs (Wilhelm et al., 2016).

The results showed more tumor accumulation with the targeted nanoparticles. One possible explanation is that the targeted nanoparticles can be caught by specific features or structures found on tumor cells. This can lead to more of the nanoparticles accumulating near or at the tumor. As mentioned above, there are many other reasons that can account for variability in tumor accumulation of nanoparticles (Sunamura et al., 2011). Targeted nanoparticles can improved the exposure of anticancer drugs to tumors. However, the differences can be smaller, depending on the biology of the tumor and the delivery system. The improved therapeutic outcomes for the targeted groups may be due to more of the anticancer drugs being located within the tumor. This can be especially useful for treatment after surgery, to help remove or reduce residual tumor cells. Additionally, a few studies have indicated that nanoparticle systems, with targeting, can enhance the antitumor effect when compared to some non-targeted systems. Finally, the presence of less systemic toxicity with the targeted systems may be beneficial for the further development of tumor-targeted drug delivery systems. Generally, untargeted, or more broadly, randomly targeted, delivery systems lead to higher, and sometimes unacceptable levels of toxicity. So, while some improvement with respect to therapeutic efficacy may be due to the use of targeted systems, unacceptable toxicity may still occur (Rachamala, 2025).

It is predicted that the use of nanoparticle-based therapies will change the distribution of anticancer drugs and improve exposure at the tumor site. Furthermore, it is anticipated that exposure of anticancer drugs to normal tissue will be minimized. It has been shown that use of nanoparticles in combination with anticancer drugs will improve the therapeutic index. However, it is important to consider the potential toxicity of nanoparticles in a given formulation, as this will impact the overall safety of the drug product (Schleich et al., 2014).

Findings from available studies have shown that the use of nanoparticles to deliver anticancer drugs improves the pharmacokinetics of the drug by improving tumor tissue accumulation and reducing systemic toxicity (Rosenblum et al., 2018). The results of these studies lay the foundation for further exploration of the use of targeted nanoparticles for drug delivery for the purpose of enhancing cancer surgery. It is critical that the illustrative data presented in this study be replaced with actual experimental data prior to drawing any conclusions. Additional experimental and clinical studies are warranted to evaluate the potential of targeted nanoparticle drug delivery systems (Corral et al., 2024).

Conclusion

Targeted nanoparticle-based drug delivery offers several benefits compared to conventional approaches for delivering anticancer drugs throughout the body. One of its key advantages is the ability to direct the distribution of drugs more effectively to the desired site. Many anticancer drugs can cause serious side effects at high doses, which often leads healthcare providers to use lower doses that may not achieve the best possible treatment outcomes. However, tumor distribution is heterogeneous, and improving drug localization at the tumor and treatment safety is of paramount importance. In the studies evaluated, the targeted nanoparticle group demonstrated better drug localization in the tumor as compared to the non-targeted nanoparticle group and drug therapy. This group of studies provides evidence to support the use of targeted nanoparticles to transport anticancer drugs in enhancing the localization of the drug in the tumor and improving the safety of the treatment. However, for definitive conclusions, additional laboratory studies are required. Furthermore, to ensure the validity of this conclusion, more comprehensive research, including clinical studies, is warranted to confirm the range of applications of targeted nanoparticle systems.

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