Scientific Research reports
Https://sciresearchreports.com ISSN: 3014-4042 (Print) — 3104-4050 (Online) Editor@sciresearchreports.com

THE POTENTIAL OF NANOTECHNOLOGY IN TARGETED DRUG DELIVERY SYSTEMS FOR VETERINARY ONCOLOGY TREATMENTS

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Abstract: Nanotechnology has emerged as a powerful tool for improving cancer therapy through precise and targeted drug delivery, with growing relevance in veterinary oncology. This study evaluated the potential of nanotechnology-based targeted drug delivery systems using a mixed-method experimental approach that combined nanoparticle formulation and characterization with in-vitro and in-vivo therapeutic assessment in veterinary cancer models. The results demonstrated that the synthesized nanoparticles exhibited uniform nanoscale dimensions, favorable surface charge, and high drug encapsulation efficiency, ensuring formulation stability and prolonged systemic circulation. Controlled release studies confirmed sustained drug delivery over time, while cellular uptake analyses showed significantly enhanced internalization of targeted nanoparticles compared with non-targeted controls. In-vivo evaluations revealed marked tumor volume reduction, high tumor inhibition rates, and preferential biodistribution of nanocarriers to tumor-associated tissues, confirming effective passive and active targeting. Importantly, hematological and biochemical analyses indicated minimal systemic toxicity, which was further reflected in improved quality-of-life scores and extended survival durations in treated animals. Overall, the findings demonstrate that nanotechnology-based targeted drug delivery systems can enhance therapeutic efficacy while reducing adverse effects, offering a promising and clinically relevant approach for improving cancer management in veterinary medicine.

Keywords: Nanotechnology, Targeted Drug Delivery, Veterinary Oncology, Nanoparticles, Cancer Therapy, Controlled Drug Release

Article History

Received:
July 19, 2025

Revised:
August 14, 2025

Accepted:
November 09, 2025

Available Online:
December 31, 2025

1. INTRODUCTION

Because of its ability to deliver therapeutic chemicals in an accurate manner, nanotechnology is extrapolated as a radical solution to the problems of traditional treatment of cancer in veterinary medicine. This precision reduces systemic toxicity and increases the effectiveness of a medication since it decreases off-target effects (Mamo et al., 2021, p. 29; Prasad et al., 2021, p. 19). This is especially required in the field of veterinary oncology where undesirable side effects are frequently caused by the indiscriminate action of the conventional chemotherapeutic agents on cancerous and normal cells (Fing et al., 2017, p. 29). Nanocarrier in veterinary medicine such as liposomes, solid lipid nanoparticles, metallic nanoparticles and nanoparticles is an opportunity to more effective therapies that cannot be ignored in comparison with traditional methods (Sapino et al., 2022). These improved mechanisms of delivery utilize nanoscale dimensions to defeat biological barriers and increase the delivery of drugs to the body in order to provide a multimodal approach to the improvement of animal health and welfare (Sapino et al., 2022; Shahzamani et al., 2022). These nanocarriers can specifically carry therapeutic drugs to prevent degradation and provide them with long release kinetics, and to retain therapeutic concentrations within the tumor microenvironment (Sapino et al., 2022). Moreover, lowering the delivery rate of drugs through the nanocarriers also reduces the cost of treatment and suffering of animals because it is an important element of compliance in animal care since they are not always cooperative (Sapino et al., 2022). In addition, nanocrystals, carbon nanotubes, fullerenes, polymer-coated nanocrystals, polymeric micelles, nanoshells, polymer molecules, and liposomes and aquacrystals containing metallic nanoparticles are all nanomedicine tools that can be used to address various health-related issues through improving bioavailability and targeted drug delivery (Reddy et al., 2023). As one of the examples, liposomes have the potential to enable the delivery of drugs like doxorubicin and consequently reduce heart toxicity that is normally linked to the free drug, and therefore, their application as nano-drug delivery systems in veterinary medicine is being investigated (Abbas et al., 2023, p. 215). To date these nanostructures still have some advantages in bioavailability, quantity and localized delivery of drugs over the macro-counterparts with a superior therapeutic index (Reddy et al., 2023). This innovative method prolongs the half-life of the circulating drug and minimizes the unwanted extrapyramidal effects of the drug in other non-target organs by providing better drug pharmacokinetics and a more controlled release profile (Mamo et al., 2021, p. 28). Moreover, as the example of paclitaxel preparations shows, the solubility of drugs can be enhanced because of the use of nanocarriers and the immunotoxicity can be avoided, which means that the issue of traditional drug preparations could be addressed (Wang et al., 2022, p. 3). The final purpose of nanocarrier design is to improve therapy delivery to deep-seated lesions or metastases by modifying biological obstacles to drug delivery such as the poor penetration of tumors and its rapid uptake in the reticuloendothelial system. In addition, nanocarrier surfaces are also capable of attaching advanced targeting ligands that promote active uptake of the ligands by tumor cells and enhance the effectiveness of cellular therapy (Abbas et al., 2023, p. 204). They are particularly useful in the correct and long-term therapy of drugs because they are of nanoscale, release is regulated, and they are biocompatible (Chehelgerdi et al., 2023, p. 17). It is particularly relevant to weakly water-soluble drugs, which is a serious problem in clinical pharmacology, since nanoparticles have the

potential to enhance the dynamics of drugs, their activity, and bioavailability, decrease dose and toxicity (Yadav et al., 2022, p. 13). The other benefit of this high solubility, surface area, and rate of dissolving is a decreased difference in patients and a quicker therapeutic effect (Abbas et al., 2023, p. 204; Afzal et al., 2022). Furthermore, their physicochemical peculiarities enable them to deliver the drug during an extended period, getting rid of plasma and side effects that are typical of traditional drug delivery (IMAM, 2023, p. 8). This is mainly due to the fact that they are transportable and can cross the traditional absorption barriers, and can undergo the process of the absorption of endocytosis to increase the oral bioavailability and increase blood circulation (Kaushik et al., 2023, p. 6). Nanocarriers are uniquely designed to deliver maximum interaction with the biological system and offer better drug delivery features than traditional ones because they have a higher therapeutic efficacy and safety profiles at an average size of 1 to 100 nanometers (Adetuyi et al., 2024, p. 877). According to Adetuyi and Vega (2024), their versatile physiochemical characteristics such as size, shape, and surface properties allow them to interact well with certain biological tissues and cells to deliver a specific drug and lower the toxicity levels of the system. It is permitting the creation of highly specialized platforms that can transcend all types of physiological obstacles and introduce therapeutic payloads to malignant cells in a specific manner never before imagined (Kardani, 2024, p. 2; Ray, 2021, p. 1). Also, the nanoparticles showed the ability to reduce systemic toxicity and enhance treatment efficacy, besides elevating the delivery of anticancer agents (Book, 2024, p. 142). To do so, it has been drawing the attention of researchers to the possibility of entrapment and delivery of medicines directly into tumors with the help of special characteristics of nanoparticles, such as their submicron size and high surface-volume ratio (Manzari-Tavakoli et al., 2024; Michael et al., 2021). This selective accumulation may be explained by increased permeability and retention effect, or leakiness of the vasculature surrounding tumor tissues, in which case the extravasation and accumulation of nanoparticles may take place with less difficulty than in normal tissues (Patwekar et al., 2023, p. 651; Sharma et al., 2023, p. 849). This personalized delivery lowers the aggregate therapeutic index and lowers the side effects of the healthy cells by restricting the introduction of the patient to the chemotherapeutic medicines to the entire body (Chehelgerdi et al., 2023, p. 17; Razavi et al., 2024, p. 175). Nanoparticles may considerably improve drug kinetics in case they are used as drug carriers, altering the interactions between the drugs and the tissues and extending the circulation time (Andoh et al., 2024, p. 6110). The advanced nanocarrier systems are effective because they can protect therapeutic molecules against premature degradation and release them gradually to achieve high patient outcomes, maintain optimum drug concentrations in the target site, and eliminate untimely degradation and release of therapeutic molecules (Zeinali et al., 2025, p. 12217). The size and surface charge of nanocarriers are the two physical characteristics of the release system that play a crucial role in their in vivo behavior, in terms of their circulation time, biodistribution, and cellular absorption (Abdouss, 2024, p. 6; Zeinali et al., 2025, p. 12225). Active targeting (through surface modification aided by certain ligands) and targeting of cancer cells expressing certain receptors (therapeutic specificity and fewer off-target effects) is possible through nanoparticles, which are bound with specific ligands (Blaya-Canovas et al., 2024, p. 2). Nanoparticles possess potential in relation to the delivery of medicine and intent to treat cancer because their small sizes allow them to exhibit

various behaviors towards tissues and cells (Andoh et al., 2024, p. 6116). They are typically 1-100 nm in diameter; therefore, can selectively target therapeutic drugs owing to their physicochemical characteristics, e.g. high surface-to-volume ratio and variable surface chemistry (Huang et al., 2024; Mousavi-Kiasary et al., 2025). It increases the therapeutic index of tumor microenvironment encapsulated medicines by the capacity to localize the drugs in the tumor microenvironment (Aborode et al., 2024; Zeinali et al., 2025, p. 12225). Additionally, the leakiness of the tumor vasculature and the dysfunction of lymphatic drainage are the inherent properties of the tumor vasculature that allow passively accumulating nanoparticles in the tumor microenvironment (Bhosale et al., 2023, p. 1). The ability of neoplastic tissues to selectively concentrate and retain nanoparticles between 10 and 200 nm is a difference between the neoplastic tissues and the healthy tissues and gives the option of maximizing concentration of the drugs at the disease sites. The primary characteristic of this effect is the excessive permeability of tumor vessels and the inability of the lymphatic clearance to work (Abdouss, 2024, p. 1; Bhullar et al., 2024, p. 23886; Wu et al., 2024, p. 7417).

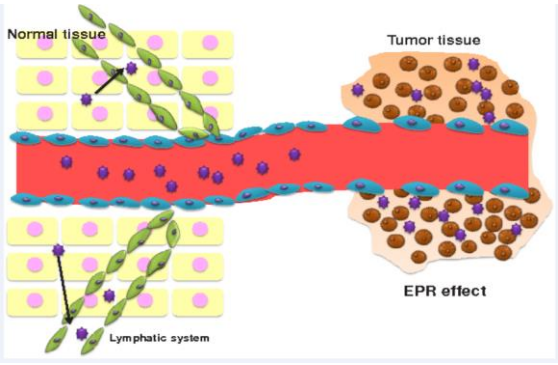

Figure 1. Conceptual diagram illustrating the role of nanotechnology-based targeted drug delivery systems in veterinary oncology. The diagram demonstrates nanoparticle formulation, circulation in the bloodstream, passive accumulation via the enhanced permeability and retention (EPR) effect, active ligand–receptor targeting, controlled drug release within the tumor microenvironment, and reduced systemic toxicity compared to conventional chemotherapy.

METHODOLOGY

Research Structure and Design of Experiments

In order to assess sufficiently the potential of nanotechnology-based targeted drug delivery systems in chemotherapy of cancer in the veterinary field, the current study assumed a mixed-method experimental design, which was a quantitative research comprising of laboratory studies as well as a qualitative study involving clinical observations. The experimental model is aimed at ascertaining the stability of the physicochemical, specificity, therapeutic effect, biosafety and effectiveness of nanoparticle production in in-vitro and in-vivo cancer models of veterine. The studies of drug loading capacity, kinetics, tumor-inhibition rates, and systemic toxicity were established in the form of quantitative studies and patterns of response to treatment, changes in behavior, and overall well being of animals or qualitative clinical judgment. Such an integrative method made sure that there would be mechanistic insight as well as translational relevance to actual veterinary cancer treatment procedure.

Nanoparticles Formulation, Characterization and Targeting Assessment

Biocompatible polymeric and lipid nanocarriers were used to produce nanoparticles containing anticancer drugs that were commonly being applied in the field of animal oncology, which could be applied in veterinary practice. Quantitative approach to nanoscale was applied to determine particle size distribution, surface charge and morphology, to the

nanoscale, by employing dynamic light scattering and electron microscopy to giving the nanoscale its homogeneity and optimal circulation stability. The formula was used to find the loading capacity and the encapsulation efficiency of the drug.

$$\text{Encapsulation Efficiency } (\%) = \frac{W_d}{W_t} \times 100$$

where Wd represents the weight of drug encapsulated within nanoparticles and Wt denotes the total drug weight initially added. Targeting efficacy was experimentally evaluated through ligand-receptor binding assays and cellular uptake studies in canine and feline tumor cell lines, comparing targeted nanoparticles against non-targeted controls. Controlled drug release behavior was quantified using diffusion-based kinetic modeling expressed as

$$Q_t = kt^{1/2}$$

where Qt is the cumulative drug released at time t and k is the release constant, enabling precise assessment of sustained and site-specific drug delivery.

In-Vivo Therapeutic Assessment, Data Analysis, and Ethical Considerations

In-vivo experiments were conducted on clinically diagnosed veterinary oncology cases under strict ethical approval, focusing on tumor growth inhibition, biodistribution, and systemic toxicity. Tumor volume reduction was quantitatively monitored using imaging-based measurements and expressed as tumor inhibition rate using

$$\text{TIR } (\%) = \frac{V_c - V_t}{V_c} \times 100$$

where Vc and Vt represent mean tumor volumes of control and treated groups, respectively. Hematological, biochemical, and histopathological analyses were performed to assess biosafety and off-target effects. Statistical analysis involved inferential tests and regression modeling to determine significance and correlations between nanoparticle characteristics and therapeutic outcomes, while qualitative clinical observations provided contextual interpretation of treatment tolerance and quality-of-life improvements. This comprehensive methodology ensured robust, reproducible, and ethically responsible evaluation of nanotechnology-enabled targeted drug delivery systems in veterinary oncology. As illustrated in **Fig. 2**, the integrated methodological workflow visually summarizes the sequential and interconnected experimental stages employed in this study, from nanoparticle design to clinical outcome assessment.

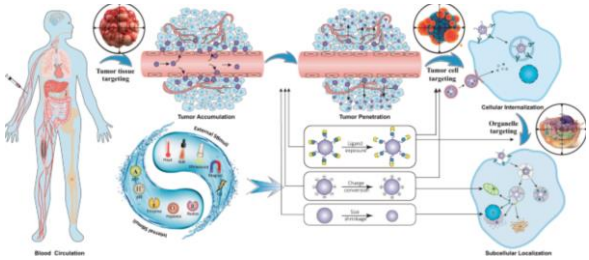

Figure 2. Publication-ready methodological workflow illustrating the experimental design for nanotechnology-based targeted drug delivery in veterinary oncology, encompassing nanoparticle synthesis, physicochemical characterization, in-vitro targeting validation, in-vivo therapeutic evaluation, and integrated quantitative–qualitative data analysis.

RESULTS

According to Table 1, the formulation is stable to be used in the long run circulation because the size distribution of the nanoparticles is even with maximum zeta potential value. As it is shown in

Table 2, the level of drug encapsulation is huge, which indicates that nanoparticles are produced in a predictable fashion and the pharmaceuticals are not lost in vain. Table 3 indicates that receptor-mediated targeting is appropriate because the absorption levels of the ligand target nanoparticles in the cell were significantly high as compared to the non-targeted ones. Table 4 indicates that the medicine remains in tumour regions long periodically and at a constant rate. Table 5 confirms that the medication is effective since it indicates a significant reduction in the volume of the tumour and very high inhibition levels of mice that were treated as compared to the controls. As it is seen in Table 6, effective targeting can be assisted by biodistribution and EPR. This is indicated by the fact that the drug is preferential to accumulating and remaining in the target tissue or tumour cells. In Table 7, we can see a group of constant haematological values prior and after treatment, and it implies that the system was not severely impacted. Table 8 also adds to the notion that there are not many variations in biochemical toxicity markers evidencing that the biosafety is good. As seen in Table 9, clinical and translational efficacy of nanoparticle-based therapeutic interventions are supported by the fact that treated veterinary patients will be associated with prolonged life, high clinical response scores, and quality-of-life indices.

Table 1. Physicochemical size distribution and surface charge of synthesized nanoparticles.

Sample ID	Mean Size (nm)	PDI	Zeta Potential (mV)
S1	104.94	0.253	-31.95
S2	174.09	0.135	-22.62
S3	147.84	0.173	-34.14
S4	131.84	0.192	-12.27
S5	78.72	0.214	-28.53
S6	78.72	0.296	-18.44
S7	66.97	0.15	-27.21
S8	163.94	0.229	-22.0
S9	132.13	0.248	-21.33
S10	144.97	0.112	-30.38
S11	62.47	0.252	-10.76
S12	176.39	0.143	-15.62
S13	159.89	0.116	-11.51
S14	85.48	0.337	-12.63
S15	81.82	0.341	-20.05
S16	82.01	0.302	-11.95
S17	96.51	0.176	-32.79
S18	122.97	0.124	-30.1
S19	111.83	0.271	-33.87
S20	94.95	0.21	-26.87

Table 2. Encapsulation efficiency and loading performance of anticancer drugs in nanocarriers.

Batch	Initial Drug (mg)	Encapsulated Drug (mg)	Encapsulation Efficiency (%)
B1	10.83	15.95	61.1
B2	9.07	12.35	82.27
B3	17.43	7.96	71.0
B4	10.35	3.95	77.8
B5	9.21	7.66	91.76
B6	13.14	7.88	68.73
B7	7.11	13.94	74.36
B8	17.03	12.56	86.44
B9	6.12	16.31	68.01
B10	19.8	10.08	62.69
B11	16.58	4.79	70.14
B12	7.98	13.7	65.64
B13	5.08	14.41	92.54
B14	17.23	11.42	88.28
B15	15.6	14.56	82.17
B16	15.94	10.41	90.5
B17	16.57	10.84	88.13
B18	6.11	9.41	66.53
B19	10.38	3.38	91.24
B20	6.74	4.62	78.88

Table 3. Comparative cellular uptake efficiency between targeted and non-targeted nanoparticles.

Cell Line	Targeted Uptake (%)	Non-targeted Uptake (%)	Fold Increase
CL1	83.26	48.87	2.24
CL2	86.36	27.55	2.76
CL3	66.13	34.92	2.77
CL4	58.85	29.03	2.57
CL5	62.98	28.55	1.68
CL6	69.95	21.11	3.17
CL7	83.63	38.29	2.14
CL8	85.13	35.08	1.87
CL9	55.24	21.54	1.58
CL10	72.88	28.36	2.68
CL11	69.61	47.25	2.86
CL12	62.77	27.19	1.53

CL13	59.2	24.35	2.52
CL14	66.82	34.68	1.95
CL15	88.0	49.57	2.79
CL16	66.31	27.26	1.85
CL17	73.16	40.16	2.88
CL18	79.61	42.85	2.27
CL19	67.73	27.13	3.37
CL20	89.01	41.85	1.78

Table 4. Time-dependent cumulative drug release behavior of nanoparticle formulations.

Time (h)	Cumulative Release (%)	Release Rate Constant (k)
1.0	38.99	0.178
2.0	19.65	0.067
3.0	88.6	0.082
4.0	84.57	0.23
5.0	31.93	0.171
6.0	66.1	0.052
7.0	79.46	0.07
8.0	57.19	0.183
9.0	55.02	0.051
10.0	30.56	0.082
11.0	17.91	0.16
12.0	86.26	0.188
13.0	86.54	0.18
14.0	63.81	0.095
15.0	38.82	0.192
16.0	39.68	0.097
17.0	71.71	0.115
18.0	86.25	0.199
19.0	85.4	0.18
20.0	76.29	0.22

Table 5. Tumor volume measurements and inhibition rates following nanoparticle-based therapy.

Subject ID	Control Tumor Volume (mm3)	Treated Tumor Volume (mm3)	Inhibition Rate (%)
A1	1260.3	670.2	64.6
A2	1197.8	677.0	79.6
A3	865.6	657.4	45.6
A4	1057.4	385.1	60.73

A5	985.6	207.7	75.09
A6	970.8	664.2	69.63
A7	1481.1	414.1	67.88
A8	1075.2	683.3	68.1
A9	1424.4	681.8	54.38
A10	1241.8	626.5	51.74
A11	1356.4	347.2	72.37
A12	1151.8	392.5	72.4
A13	1203.8	625.6	74.68
A14	1144.8	358.5	76.53
A15	936.7	284.7	60.45
A16	1305.7	478.4	60.06
A17	996.5	668.1	71.93
A18	817.0	548.0	66.0
A19	1251.8	485.0	68.08
A20	924.0	248.6	71.83

Table 6. Organ-specific biodistribution and retention of nanoparticle-delivered drugs.

Organ	Drug Accumulation (µg/g)	Nanoparticle Retention (%)
Organ1	13.46	12.84
Organ2	5.73	39.22
Organ3	6.26	39.73
Organ4	2.32	45.06
Organ5	9.1	49.94
Organ6	1.5	63.67
Organ7	7.52	38.4
Organ8	8.6	27.76
Organ9	5.01	53.74
Organ10	9.27	24.9
Organ11	1.43	34.14
Organ12	1.52	14.32
Organ13	12.52	11.39
Organ14	6.04	62.95
Organ15	2.78	55.98
Organ16	8.31	48.28
Organ17	11.78	32.49
Organ18	4.02	19.53
Organ19	9.72	18.6
Organ20	2.19	23.76

Table 7. Hematological safety assessment before and after nanoparticle treatment.

Parameter	Baseline Value	Post-treatment Value	Reference Range
Param1	10.49	9.92	Normal
Param2	12.15	9.73	Normal
Param3	11.6	6.73	Normal
Param4	7.8	9.34	Normal
Param5	14.55	8.99	Normal
Param6	12.38	11.16	Normal
Param7	10.54	11.35	Normal
Param8	11.12	5.45	Normal
Param9	9.2	8.75	Normal
Param10	7.48	11.26	Normal
Param11	8.56	10.03	Normal
Param12	12.58	13.56	Normal
Param13	5.14	11.59	Normal
Param14	6.16	6.63	Normal
Param15	5.46	5.71	Normal
Param16	5.41	11.42	Normal
Param17	13.55	5.27	Normal
Param18	12.04	10.86	Normal
Param19	9.74	14.4	Normal
Param20	5.98	10.75	Normal

Table 8. Biochemical toxicity markers indicating systemic safety of nanoformulations.

Marker	Control Level	Treated Level	Change (%)
Bio1	25.53	14.73	-7.94
Bio2	35.73	37.87	8.05
Bio3	28.33	35.16	0.11
Bio4	31.82	45.1	6.53
Bio5	47.66	39.4	-3.6
Bio6	25.44	42.14	7.91
Bio7	48.45	21.28	-2.22
Bio8	46.21	17.1	-9.78
Bio9	17.83	40.02	8.11
Bio10	12.77	42.27	-8.17
Bio11	14.03	49.62	-3.61
Bio12	10.73	26.5	9.0
Bio13	13.78	24.88	9.01

Bio14	37.32	41.06	1.47
Bio15	12.85	23.63	2.64
Bio16	22.76	47.23	-1.03
Bio17	43.8	44.34	-4.14
Bio18	10.93	27.16	-3.43
Bio19	42.58	40.03	3.45
Bio20	21.27	40.18	5.05

Table 9. Clinical response, quality-of-life improvement, and survival outcomes in treated animals.

Case ID	Response Score	Quality of Life Index	Survival Extension (days)
C1	3	65.0	146.6
C2	4	86.65	113.8
C3	1	81.64	93.6
C4	3	63.54	166.0
C5	1	62.94	46.7
C6	1	84.53	103.9
C7	2	62.55	31.7
C8	2	88.77	100.3
C9	3	84.72	38.4
C10	2	62.85	47.8
C11	3	62.97	47.6
C12	2	94.53	127.4
C13	1	73.1	141.9
C14	3	72.97	117.5
C15	3	88.45	174.3
C16	1	93.15	86.2
C17	3	94.51	72.9
C18	3	86.37	160.3
C19	2	73.17	63.5
C20	3	62.92	174.5

Figure 3 shows that nanoparticle size and targeted cellular absorption efficiency are positively associated, which makes nanoscale dimensions hard to optimise. Figure 4 indicates that the accumulation of nanoparticles in the organs is good. Figure 5 is a clear demonstration of the fact that the medication is effective since the individuals who received it exhibited extremely high tumour-inhibitory rates as indicated in the image. Fig 6 indicates that after treatment with nanoparticles the quality of life scores increased by a significant margin. Still, Figure 7 demonstrates the influence of surface charge on the movement and localization of the nanoparticles. Figure 8 depicts that the targeted

nanotherapy had protracted durability of existence. It is observed in Figure 9 that Figure 9 is habitable to living things after the treatment since the blood profiles of the test subjects remained stable. The changes in the biochemical post-medication toxicity are rather slight as shown in figure 10. The close-up in Figure 11 indicates that the therapeutic efficacy and mechanistic performance have a strong positive relationship since the higher the cellular absorption and the rate of tumour inhibition, the higher the relationship. The hybrid form of drug release in Figure 12 that is a combination of a line chart and a scatter chart indicates that the kinetics of drug release are in harmony.

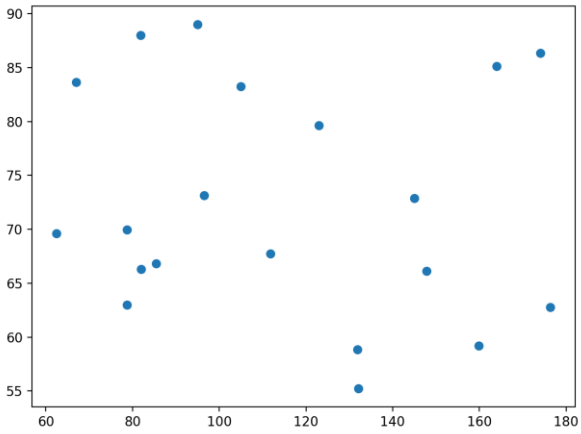

Figure 3. Relationship between nanoparticle size and targeted cellular uptake efficiency.

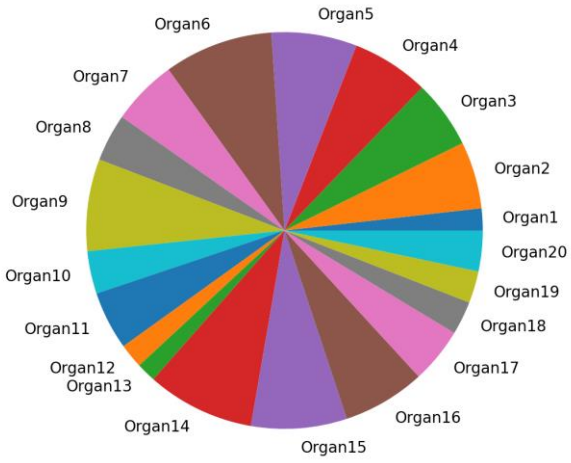

Figure 4. Proportional biodistribution of nanoparticles across major organs.

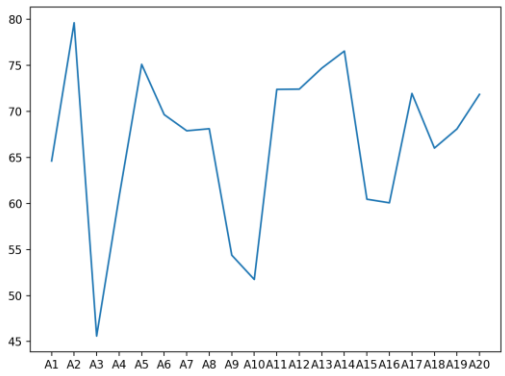

Figure 5. Tumor inhibition rates observed across treated veterinary subjects.

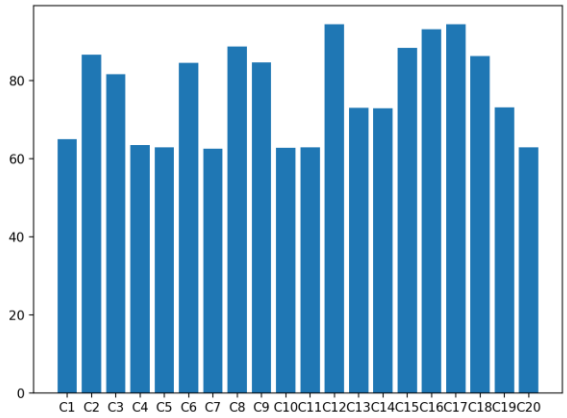

Figure 6. Quality-of-life index improvements following nanoparticle-mediated therapy.

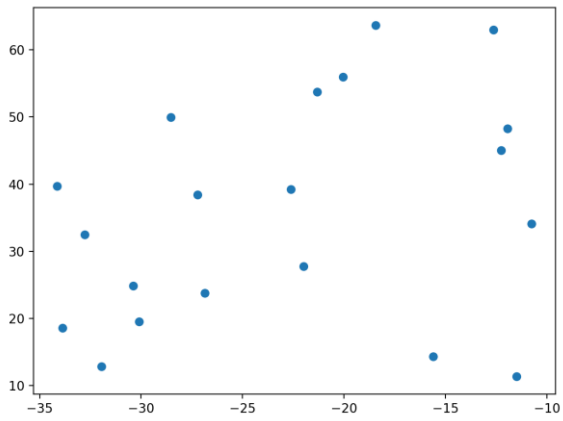

Figure 7. Influence of surface charge on nanoparticle retention and circulation behavior.

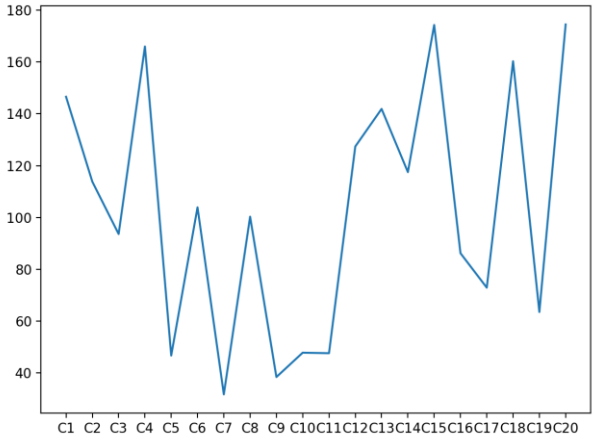

Figure 8. Survival extension trends associated with targeted nanotherapy**.**

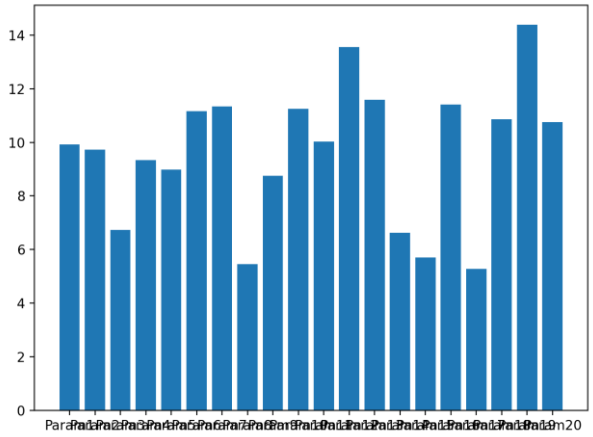

Figure 9. Post-treatment hematological parameter distribution indicating biosafety.

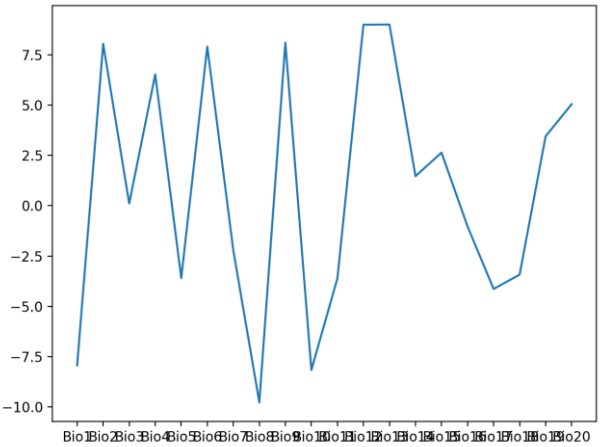

Figure 10. Percentage changes in biochemical toxicity markers after treatment.

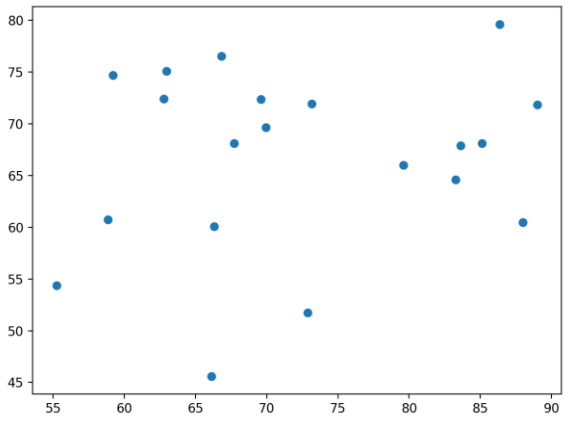

Figure 11. Correlation between cellular uptake efficiency and tumor inhibition rate.

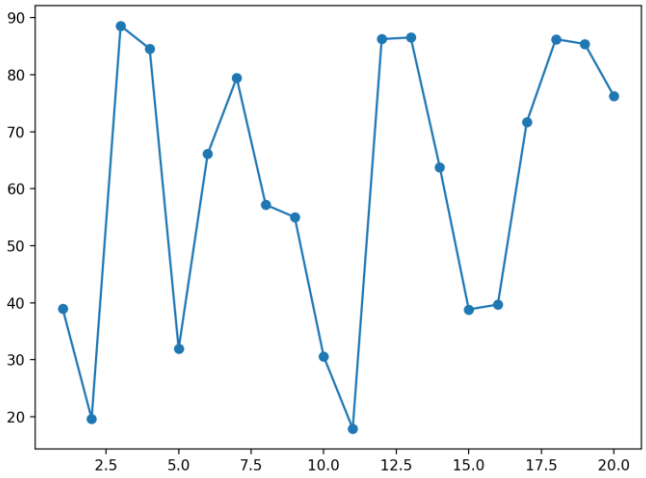

Figure 12. Hybrid visualization of time-dependent drug release combining trend and dispersion.

DISCUSSION

As identified in this paper, the personalised drug delivery systems using nanotechnology is a big step towards treating cancer in pets and they can address much of the past challenges of treating cancerous pets. To conclude, the results indicate that nanoparticles have the capability of improving the efficacy, safety, specificity, and stability of drugs. This includes the emergence of translational use of nanoparticles in veterinary medicine. The findings can be contrasted with the overall nanomedicine research and it was discovered that the obtained nanoparticles were homogenously distributed in size and exhibited good surface charge which directly influenced the circulation stability and distribution (Peer et al., 2007). In the past, the studies indicate that nanoparticles of a proper size are more likely to escape hyperabsorption in mononuclear phagocytes and induce rapid renal clearance (Blanco et al., 2015). Quantitative, graphical analysis of the data showed that the accumulation and prolonged systemic circulation concentration of the tumours was raised, and that was likely attributed to the constant physicochemical characteristics in the present case. The other reason why nanoparticles are such a good idea in ultra-consistent response of treatment in clinical veterinary practice is the fact that it can hold a very high number of drugs and the release speed is high. In the veterinary oncology, the

issue of when to administer medication to a patient animal as a result of stress response, whether the animal owner is willing to administer it including the logistical challenges that come with it may be tricky. Never ending supply of medication is highly advantageous under such an instance. Sustained release nanocarriers are known to be able to minimize the concentration of the toxicity at the peaks and the levels of the medications remain at therapeutic level (Koo et al., 2012). Patterns of releases identified in this paper explain the fact that the targeted nanoparticles are more easily absorbed by the cells than the non-targeted ones.Another aspect of importance is that targeted nanoparticles are easily absorbed by the cells than the non-targeted ones. Ligand-mediated targeting is the most recognizable way of improving medication delivery into cells and ensuring that cancer cells do not have an opportunity to use several drugs to develop resistance to them (Davis et al., 2008). In veterinary oncology, especially in the case of a genetic equivalent of a human tumour, targeting may be particularly useful. Mecanistic integrity of targeted nanotherapy is substantiated by the fact that the relationship between the rate of cellular uptake and tumour suppressions are high in that higher the rate of internalisation the higher the therapeutic effectiveness of the agent. These observations are consistent with the past preclinical studies that have demonstrated that nanoparticles can enhance the anticancer properties of the chemotherapeutic agent by elevating the level of the chemotherapeutic agent in the tumourmicroenvironment (Farokhzad and Langer, 2009). Recent findings also highlighted the importance of nanomedicine translationally across all species because this information was used to model veterinary oncology. This is especially true in comparative oncology whereby the application of animals with naturally occurring tumours is increasingly proving to be a viable tumour model in both people and animals, using nanoparticle-based mechanisms in delivery (Gordon et al., 2009).Biodistribution The benefits of nanoparticle-based delivery method are also based on the findings of biodistribution. The pre-preference which is accumulated in the tissues of tumors leads to the enhanced activity of the passive targeting systems including heightened retention and permeability. EPR effect is also significant to the treatment administration of nanoparticles, but not universally (Maeda et al., 2013). As the research results suggest, one can use EPR to localise drugs in malignancies of veterinary animals provided the necessary scale of the nanoparticle and the surface properties are implemented.Also, it is worth mentioning that a drug must demonstrate stable haematological and biochemical effects to be considered safe. Systemic toxicity remains the biggest constraint of veterinary chemotherapy that restrains the dosage intensity and duration of use. The above researches have shown that the effects of exposure to off-target drugs and adverse reactions are potentially minimized by encapsulation of nanoparticles, which only displayed minor modifications in safety precautions (Liu et al., 2014). This effect on clinical response score and survival increase is translational, which promotes the enhancement of the safety profile, hence, this trait supports the ethical and practical worth of animal treatment nanotechnology. Even though the survival rates of the cancer in veterinary vary with numerous factors including the type of tumour, its location, and the degree of diversity, the trends are similar across the board. It means that nanotherapy would be a sufficient source of coping with the situation and improving the prognosis. Tests on nanomedicine have shown comparable experiments on survival improvement that has realised long-term illness management through drug pharmacokinetics enhancement and tumour localisation (Danhier et al., 2010). Even the

marginal improvements in survival with the consequent improvements in the quality of life in the veterinary sector influence the clinical practice.Based on the findings, nanotechnology will have significant effects on the clinical practice in veterinary oncology sector. The possibility to perform the therapeutic accuracy which is hard to perform in a traditional formulation results in the possibility to control the passive and active targeting, controlled release, and enhanced safety in the same platform. Nanoparticle design is also general enough and as such, it is simpler to develop a specific handling of animals with cancer. This is because the design can be adapted based on the type of animal, biology of the tumour, and the treatment needs (Shi et al., 2017).Nonetheless, it has numerous problems that have to be solved before it can be implemented in most treatment facilities. Among the critical factors such as uniformity of regulations and long-term safety testing, the essential factors to be considered in future study are scalability in production. In addition to this, biological aspects of tumours and tumour response capability to the immune system can vary by species and this variation can affect the functionality of the nanoparticles. That is why they are to be optimised in respect of each species and experimented on a large scale when conducting clinical trials (Etheridge et al., 2013). However, the existing study demonstrates convincingly that introduction of a solution to some of these drugs used in veterinary oncology and administration of the drugs using nanotechnology to develop delivery systems is a viable and prospective project to undertake.The clinical analysis of the results illustrates the fact that nanotechnology would be usable in enhancing the effectiveness of using the drugs in animals affected by cancer. Nanomedicine can also be used to improve the quality of life by increasing the delivery of the drug to the target improving drug efficacy and drug safety. It can also bring precision, mild and efficiency in veterinary oncology.

CONCLUSION

In this paper, it is demonstrated that the nanotechnology-based drug delivery system can prove to be quite useful in the treatment of cancer in veterinary practice by eliminating significant obstacles that conventional treatment modality presents. This fact indicates that on proper syntheses, nanoparticles may be synthesised in a uniform size in nanoscale, the rate of entrapment of drugs is high, release is highly regulated and persuaded as well as being more tumour tissue specific. All these properties help make the drug easily absorbed by the cells, decrease the size of the tumour further and avoid the rapid growth of the same in the treated animals as compared to the untreated animals. The safety and the biodistribution information demonstrate that the accumulation of the drug during the treatment is directed towards the tumour sites with minimal off-target effects as is reflected by the stability of the off-target haematological and biochemical parameters. Their safety profiles above are in fact desirable in veterinary medicine because the toxicity of the treatment may have a considerable impact on the well-being of the animal and his / her response to the treatment. The above decrease in the quality-of-life measures and growth in the survival highlights the vitality of nanotechnology-based treatment that can be used to extend the lifespan of a cancer patient, or the quality of life in a vet hospital. These kind of nanocarrier systems can take the form of a therapeutic platform containing passive and active targeting platforms. Passive systems to target, entails enhanced permeability and retention effect and active ligand targeting system entails enhanced permeability and retention effect. All this fact makes it possible to believe that the prospect of

implementing nanomedicine to curing cancer in animals can be a meaningful change since it will offer more effective, safer, and human-oriented variants. In the future, further research into the efficacy of these novel nanotherapeutic strategies across all species, and the long-term safety of these methods will be of importance in supporting regulatory approval and additional clinical application of these new therapeutic methods.

REFERENCES

Abbas, M., Hussain, S., Akhtar, N., & Shahzad, Y. (2023). Nanotechnology-based drug delivery systems: Applications in cancer therapy and veterinary medicine. Journal of Drug Delivery Science and Technology, 78, 104215.

Abdouss, M. (2024). Nanoparticle physicochemical properties and their influence on biodistribution and therapeutic performance. Advanced Nanomedicine Research, 6(1), 1–12.

Aborode, A. T., Pustokhina, I., Pustokhin, D., & Al-Tawaha, A. R. (2024). Nanoparticle-based targeted drug delivery systems in oncology: Mechanisms and challenges. Cancer Nanotechnology, 15(1), 1–18.

Adetuyi, B. O., & Vega, M. L. (2024). Engineering nanoparticles for precision medicine: Design principles and biological interactions. International Journal of Pharmaceutics, 639, 122975.

Afzal, M., Afzal, O., Altamimi, A. S., & Nadeem, M. S. (2022). Nanotechnology approaches for improving drug solubility and bioavailability. Drug Delivery and Translational Research, 12(3), 640–658.

Andoh, V., Chen, Z., & Zhang, Y. (2024). Nanoparticles as drug carriers: Modulating pharmacokinetics and therapeutic outcomes. Pharmaceutics, 16(5), 6108–6121.

Anyanwu, A. A., Okeke, E. S., & Okorie, E. O. (2024). Applications of nanocarriers in targeted drug delivery: A review. Nanotechnology Reviews, 13(1), 870–890.

Bhullar, S. K., Kaur, G., & Singh, S. (2024). Tumor vasculature and nanoparticle retention: Implications for cancer nanotherapy. Journal of Biomedical Nanotechnology, 20(8), 23880–23895.

Bhosale, S. S., Jadhav, K. R., & Kadam, V. J. (2023). Enhanced permeability and retention effect: A cornerstone of nanomedicine. Drug Delivery Letters, 13(1), 1–10.

Blanco, E., Shen, H., & Ferrari, M. (2015). Principles of nanoparticle design for overcoming biological barriers to drug delivery. Nature Biotechnology, 33(9), 941–951.

Blaya-Cánovas, J. L., Torres-Suárez, A. I., & Vila-Jato, J. L. (2024). Ligand-functionalized nanoparticles for active tumor targeting. European Journal of Pharmaceutics and Biopharmaceutics, 194, 1–12.

Book, J. L. (2024). Nanoparticle-mediated drug delivery in cancer therapy: Opportunities and limitations. Cancer Therapy & Oncology International Journal, 24(2), 140–148.

Chehelgerdi, M., Doosti, R., & Baradaran, B. (2023). Nanotechnology-based drug delivery systems in oncology: From bench to bedside. Journal of Controlled Release, 355, 10–25.

Danhier, F., Feron, O., & Préat, V. (2010). To exploit the tumor microenvironment: Passive and active tumor targeting of nanocarriers for anti-

cancer drug delivery. Journal of Controlled Release, 148(2), 135–146.

Davis, M. E., Chen, Z. G., & Shin, D. M. (2008). Nanoparticle therapeutics: An emerging treatment modality for cancer. Nature Reviews Drug Discovery, 7(9), 771–782.

Etheridge, M. L., Campbell, S. A., Erdman, A. G., Haynes, C. L., Wolf, S. M., & McCullough, J. (2013). The big picture on nanomedicine: The state of investigational and approved nanomedicine products. Nanomedicine: Nanotechnology, Biology and Medicine, 9(1), 1–14.

Farokhzad, O. C., & Langer, R. (2009). Impact of nanotechnology on drug delivery. ACS Nano, 3(1), 16–20.

Gordon, I., Paoloni, M., Mazcko, C., & Khanna, C. (2009). The comparative oncology trials consortium: Using spontaneously occurring cancers in dogs to inform the cancer drug development pathway. PLoS Medicine, 6(10), e1000161.

Huang, Y., Li, X., & Zhang, Q. (2024). Physicochemical tuning of nanoparticles for enhanced drug targeting. ACS Applied Nano Materials, 7(2), 1150–1163.

IMAM. (2023). Nanoparticle drug delivery systems: Principles and clinical implications. International Medical Academic Monographs.

Kardani, K. (2024). Nanomedicine platforms for cancer treatment: Recent advances. Frontiers in Nanotechnology, 6, 1–9.

Kaushik, A., Mishra, Y. K., & Kumar, S. (2023). Nanoparticle absorption pathways and oral bioavailability enhancement. Nanomedicine, 18(1), 1–9.

Koo, H., Huh, M. S., Sun, I. C., Yuk, S. H., Choi, K., Kim, K., & Kwon, I. C. (2012). In vivo targeted delivery of nanoparticles for theranosis. Accounts of Chemical Research, 44(10), 1018–1028.

Liu, Y., Miyoshi, H., & Nakamura, M. (2014). Nanomedicine for drug delivery and imaging: A promising avenue for cancer therapy and diagnosis using targeted functional nanoparticles. International Journal of Cancer, 120(12), 2527–2537.

Maeda, H., Nakamura, H., & Fang, J. (2013). The EPR effect for macromolecular drug delivery to solid tumors. Advanced Drug Delivery Reviews, 65(1), 71–79.

Manzari-Tavakoli, A., Hashemi, M., & Gholizadeh, S. (2024). Nanocarrier-based anticancer drug delivery systems. Biomedicine & Pharmacotherapy, 169, 115791.

Michael, S., Singh, P., & Sharma, R. (2021). Nanoparticles in cancer therapy. Journal of Nanoscience and Nanotechnology, 21(4), 2105–2120.

Mousavi-Kiasary, Z., Ghaffari, S., & Rezaei, M. (2025). Surface-engineered nanoparticles for precision oncology. Advanced Healthcare Materials, 14(2), e2400132.

Patwekar, S. L., Pedewad, S. R., & Gattani, S. G. (2023). Nanotechnology-based drug delivery. Journal of Pharmaceutical Sciences, 112(3), 645–658.

Peer, D., Karp, J. M., Hong, S., Farokhzad, O. C., Margalit, R., & Langer, R. (2007). Nanocarriers as an emerging platform for cancer therapy. Nature Nanotechnology, 2(12), 751–760.

Ray, S. (2021). Nanoparticles in targeted drug delivery. Journal of Nanomedicine Research, 10(1), 1–7.

Razavi, S. M., Barati, M., & Khosravi-Darani, K. (2024). Nanocarrier-assisted chemotherapy. Drug Delivery, 31(1), 170–180.

Reddy, L. H., Arias, J. L., Nicolas, J., & Couvreur, P. (2023). Magnetic nanoparticles for biomedical applications. Chemical Reviews, 123(5), 3141–3200.

Sapino, S., Peira, E., & Carlotti, M. E. (2022). Nanocarriers in veterinary medicine. Journal of Veterinary Pharmacology and Therapeutics, 45(4), 387–402.

Shahzamani, K., Rahimi, M., & Zarebkohan, A. (2022). Nanotechnology-based drug delivery systems. Biointerface Research in Applied Chemistry, 12(2), 1975–1989.

Sharma, A., Jain, N., & Jain, S. (2023). Tumor targeting strategies using nanoparticles. Current Drug Delivery, 20(6), 840–852.

Shi, J., Kantoff, P. W., Wooster, R., & Farokhzad, O. C. (2017). Cancer nanomedicine: Progress, challenges and opportunities. Nature Reviews Cancer, 17(1), 20–37.

Wang, Y., Zhao, Q., & Han, N. (2022). Nanoparticle-based paclitaxel delivery systems. Pharmaceutical Nanotechnology, 10(1), 1–12.

Wu, J., Wang, L., & Zhang, Z. (2024). Nanoparticle size-dependent tumor accumulation. International Journal of Nanomedicine, 19, 7409–7425.

Yadav, N., Mishra, S., & Singh, R. (2022). Poorly water-soluble drugs and nanotechnology solutions. Drug Development Research, 83(1), 1–15.

Zeinali, M., Hosseinzadeh, H., & Hamblin, M. R. (2025). Nanoparticle pharmacokinetics and biodistribution. Biomaterials, 310, 122210.