ResearchProposal_SamiaAzadAni - Samia Azad Ani.pdf

by Sanaul Haque

Submission date: 13-Oct-2025 11:34PM (UTC+0700)
Submission ID: 2779974734
File name: ResearchProposal_SamiaAzadAni_-_Samia_Azad_Ani.pdf (277.26K)
Word count: 1423
Character count: 8893

IARCO RESEARCH PROPOSAL 2025

Beyond the Body: Using Digital Twin to Guide Nanomedicine in Cancer Treatment

Samia Azad Ani

Bangladesh University of Engineering and Technology

Category: Senior
Grade: BSc
Country: Bangladesh
Major: Mechanical Engineering
Submission Date: September 30, 2025
Registered Email Address: anisamiaazad@gmail.com

Introduction

Cancer remains one of the life-threatening causes of mortality worldwide, causing almost 10 million deaths in 2020 [1]. Since traditional cancer treatments cannot distinguish cancerous cell from healthy ones, these often destroy healthy cells. Nanomedicine has emerged as a promising therapeutic approach for targeted drug delivery. But current nanomedicine design methodologies are largely empirical and rely heavily on trial-and-error approaches on repetitive animal testing due to the fact that nanomedicine has to face significant challenges including physiological barriers such as immune clearance, vascular transport limitations, and tumor cell membrane penetration. Sometimes, animal models fail to accurately replicate human physiology, resulting in poor translation of preclinical findings to clinical outcomes [2], [3], [4]. The integration of digital twin technology with nanomedicine represents a paradigm shift toward precision-driven cancer therapy. Digital twins, virtual replica of physical systems or organs that enable real-time simulation and prediction, have shown tremendous potential in healthcare applications [5]. However, their application in nanomedicine optimization for cancer treatment remains largely unexplored. This research addresses the critical need for a systematic, computational approach to nanomedicine design by developing a digital twin framework specifically for lung cancer treatment using liposomal doxorubicin nanoparticles. The proposed research is essential because it offers the potential to accelerate preclinical testing, reduce reliance on animal models, and ultimately enable personalized, efficient, and effective cancer treatment strategies.

Literature Review

The necessity of computational modeling in nanomedicine optimization has attracted significant attention in recent years as researchers attempt to overcome the limitations of conventional cancer therapies. Nanoparticles have shown promise in delivering therapeutic agents specifically to the tumor cells with reduced systemic toxicity [2]. Liposomal formulations, in particular, represent a milestone in clinical nanomedicine, with FDA-approved drugs such as Doxil and Onivyde providing evidence of their therapeutic potential. However, nanoparticles face multiple physiological barriers including rapid clearance by macrophages, leaky vasculature and tumor cell membrane leading to a collective reduction in delivery efficacy. To overcome these challenges, advanced strategies such as PEGylation, ligand mediated targeting, and stimulus-responsive designs have been proposed [3]. Mathematical and computational model of nanoparticle transport and adhesion dynamics in vascular systems have shown improved predictability and personalization. Recent literature shows that mechanics-based and stochastic models have the potential in predicting spatiotemporal dynamics of ligand-coated nanoparticles under physiological blood flow conditions, thereby reducing reliance on in-vivo experimentation. These advances highlight the value of simulation-driven design in optimizing nanoparticle size, shape, and binding kinetics for patient-specific therapy [4]. Parallel to nanomedicine, digital twin technology along with AI and ML has emerged as a transformative concept in oncology. Digital twins create interactive virtual replicas of patients by integrating multimodal data such as imaging,

genomics, and clinical parameters allowing to simulate disease progression [6]. Digital twin has been applied to simulate tumor progression, predict treatment responses, and personalize therapeutic regimens [7]. For instance, predictive digital twin models have been developed to optimize radiotherapy and chemotherapy dosing to improve tumor control with reduced toxicity [8]. Organ specific twins, such as lung models constructed from Computed Tomography (CT) imaging and finite element analysis (FEA) have shown promise in simulating biomechanical functions and nanoparticle transport pathways [9]. Despite these advances, the integration of nanomedicine with digital twin frameworks faces challenges due to data interoperability, physiological complexity, and ethical considerations related to patient-specific modeling [6]. Nevertheless, the convergence of nanoparticle drug delivery and digital twin technology represents a growing body of knowledge that holds the potential to accelerate precision oncology by enabling predictive, personalized, and adaptive treatment strategies [7][9].

Research Question

This study aims to explore the integration of digital twin with nanomedicine in order to accelerate therapeutic efficacy of cancer treatment. In this respect, the following questions have been addressed:

- How will digital twin technology be incorporated with nanomedicine design to optimize liposomal doxorubicin nanoparticles for personalized lung cancer treatment?
- What is the predictive accuracy of such integrated systems in forecasting therapeutic outcomes compared to conventional empirical approaches?

Methodology

The research will employ a comprehensive multi-phase methodology combining computational modeling, experimental validation against clinical data in three phases sequentially which has been schematically shown in **Figure 1**:

Phase 1: Digital Twin Framework Development: A patient-specific virtual lung model will be constructed from segmented 3D CT images at both end exhalation and end inhalation states as boundary condition. Finite element analysis (FEA) will be carried out to simulate lung biomechanics and nanoparticle transport. After creating virtual tumor microenvironment, real time patient data will be incorporated.

Phase 2: Nanomedicine Modeling and Simulation: Liposomal doxorubicin nanoparticles with variable parameters (size: 50-200 nm, surface charge, PEGylation density) will be modeled to simulate nanoparticle-tissue interactions including cellular uptake, drug release kinetics, and clearance mechanisms. Predictive algorithms will be developed for therapeutic efficacy based on nanoparticle distribution patterns.

Phase 3: Validation and Optimization: Digital twin predictions will be validated against existing liposomal doxorubicin clinical data. To optimize nanoparticle design parameters, machine learning algorithms integrated with digital twin simulations will be carried out. Finally, virtual clinical trials will be conducted to assess treatment scenarios and dosing regimens.

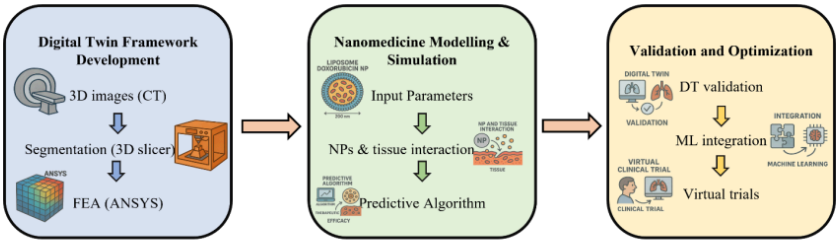

Figure 1: Integrated process flow for development of digital twin framework to guide nanomedicine model through validation.

Expected Outcomes

The project is expected to deliver a validated digital twin framework that predicts liposomal doxorubicin distribution and efficacy by optimizing nanoparticle design to achieve superior therapeutic outcomes and reduce preclinical development time. It will also evaluate the understanding of nanoparticle and tumor microenvironment interactions, enable personalized dosing algorithms as well as establish a scalable platform for broader nanomedicine applications.

Potential Limitations

The study may face technical challenges including high computational demands, dependence on imaging data quality and difficulties in integrating multi-scale biological processes as it requires complete knowledge of nano-bio interactions, tumor heterogeneity. Patient variability, complex regulatory approval, and the need for training and infrastructure may also limit rapid adoption.

Conclusion

This proposed study shows the integration of digital twin technology with nanomedicine design has the potential to optimize liposomal doxorubicin nanoparticles for personalized lung cancer therapy. By leveraging the power of simulation in refining nanoparticle design and predicting therapeutic outcomes, this approach may accelerate preclinical testing and reduce reliance on animal models.

References

[1] H. Sung *et al*., 'Global Cancer Statistics 2020: GLOBOCAN Estimates of Incidence and Mortality Worldwide for 36 Cancers in 185 Countries', *CA: A Cancer Journal for Clinicians*, vol. 71, no. 3, pp. 209–249, May 2021, doi: 10.3322/caac.21660.

[2] D. Fan, Y. Cao, M. Cao, Y. Wang, Y. Cao, and T. Gong, 'Nanomedicine in cancer therapy', Dec. 01, 2023, *Springer Nature*. doi: 10.1038/s41392-023-01536-y.

[3] O. S. Thomas and W. Weber, 'Overcoming Physiological Barriers to Nanoparticle Delivery—Are We There Yet?', Dec. 17, 2019, *Frontiers Media S.A.* doi: 10.3389/fbioe.2019.00415.

[4] S. A. Goraya *et al*., 'Modeling of spatiotemporal dynamics of ligand-coated particle flow in targeted drug delivery processes', 2025, doi: 10.1073/pnas.

[5] A. De Benedictis, N. Mazzocca, A. Somma, and C. Strigaro, 'Digital Twins in Healthcare: An Architectural Proposal and Its Application in a Social Distancing Case Study', *IEEE Journal of Biomedical and Health Informatics*, vol. 27, no. 10, pp. 5143–5154, Oct. 2023, doi: 10.1109/JBHI.2022.3205506.

[6] D. Giansanti and S. Morelli, 'Exploring the Potential of Digital Twins in Cancer Treatment: A Narrative Review of Reviews', *Journal of Clinical Medicine*, vol. 14, no. 10, 2025, doi: 10.3390/jcm14103574.

[7] S. Shen *et al*., 'From virtual to reality: innovative practices of digital twins in tumor therapy', Dec. 01, 2025, *BioMed Central Ltd*. doi: 10.1186/s12967-025-06371-z.

[8] F. Zhao *et al*., 'Current progress of digital twin construction using medical imaging', *Journal of Applied Clinical Medical Physics*, vol. 26, no. 9, pp. 1–26, 2025, doi: 10.1002/acm2.70226.

[9] L. Zhu, W. Lu, M. Soleimani, Z. Li, and M. Zhang, 'Electrical Impedance Tomography Guided by Digital Twins and Deep Learning for Lung Monitoring', *IEEE Transactions on Instrumentation and Measurement*, vol. 72, 2023, doi: 10.1109/TIM.2023.3298389.

ResearchProposal_SamiaAzadAni - Samia Azad Ani.pdf

ORIGINALITY REPORT

15%	10%	12%	0%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Austris Mazurs, Baiba Mauriņa, Dace Bandere, Konstantīns Logviss. "Targeting with toxins: an overview of venom peptides in drug delivery", International Journal of Pharmaceutics, 2025 Publication	3%
2	repositorium.uminho.pt Internet Source	2%
3	www.ijmtst.com Internet Source	2%
4	Saravanan Krishnan, A. Jose Anand, S. Sendhilkumar. "Handbook of Industrial and Business Applications with Digital Twins", Routledge, 2024 Publication	2%
5	purehost.bath.ac.uk Internet Source	1%
6	Xiaofeng Yang. "Medical Image Synthesis - Methods and Clinical Applications", CRC Press, 2024 Publication	1%
7	Filippo Dell'Anno, Roberta Giugliano, Livia De Paolis, Ines Crescio, Elisabetta Razzuoli. "Cadmium and cancer: A study on canine tumours and environmental bioindicators (Sus scrofa)", Ecotoxicology and Environmental Safety, 2025 Publication	1%

8	musculoskeletalkey.com Internet Source	1 %
9	ouci.dntb.gov.ua Internet Source	1 %
10	arxiv.org Internet Source	1 %
11	pmc.ncbi.nlm.nih.gov Internet Source	1 %
12	pubs.rsc.org Internet Source	1 %
13	Daniele Giansanti, Sandra Morelli. "Exploring the Potential of Digital Twins in Cancer Treatment: A Narrative Review of Reviews", Journal of Clinical Medicine, 2025 Publication	<1 %
14	is-innovation.eu Internet Source	<1 %
15	phys.org Internet Source	<1 %

Exclude quotes	On	Exclude matches	Off
Exclude bibliography	Off		