Nanotechnology in Cancer Immunotherapy

Momin Rijwan , Patel Anas , Sandip W Patil , Samiksha P Warke

Shree P E Tatya Patil institute of Pharmacy Jalgaon India

How to Cite this Article:

Rijwan, M., Anas, P., Patil, S. W. & Warke, S. P. (2026). Nanotechnology in Cancer Immunotherapy. International Journal of Creative and Open Research in Engineering and Management, <i>02</i>(05). https://doi.org/10.55041/ijcope.v2i5.774

https://doi.org/ 10.55041/ijcope.v2i5.774

Abstract

Cancer immunotherapy has emerged as a promising approach for cancer treatment by stimulating the body's immune system to recognize and destroy cancer cells. However, limitations such as poor drug targeting, immune suppression, and systemic toxicity reduce its effectiveness. Nanotechnology offers innovative solutions to these challenges through the use of nanoparticles and nanocarriers for targeted drug delivery and immune modulation.

Nanoparticles such as liposomes, dendrimers, polymeric nanoparticles, and metallic nanoparticles improve the delivery of immunotherapeutic agents including checkpoint inhibitors, cancer vaccines, cytokines, and gene therapies. These systems enhance drug stability, increase tumor-specific accumulation, and reduce adverse side effects. Nanotechnology also improves antigen presentation and activation of immune cells such as T-cells and dendritic cells.

Recent advancements in nano-based vaccines, gene delivery systems, and tumor microenvironment-responsive nanoparticles have shown significant potential in improving therapeutic outcomes. Despite these advantages, challenges including toxicity, large-scale production, and regulatory approval remain.

This paper reviews the role of nanotechnology in cancer immunotherapy, its mechanisms, applications, advantages, limitations, and future prospects in modern cancer treatment.

Keywords: Nanotechnology, Cancer Immunotherapy, Nanoparticles, Drug Delivery, Tumor Microenvironment, Nano-vaccines

1. Introduction

Cancer is one of the leading causes of death worldwide. Conventional therapies such as chemotherapy and radiotherapy often damage healthy tissues and produce severe side effects. Cancer immunotherapy has revolutionized treatment by activating the immune system against cancer cells. Major immunotherapy approaches include immune checkpoint inhibitors, cancer vaccines, cytokine therapy, and adoptive cell therapy.

However, several limitations affect immunotherapy, including poor targeting, low drug stability, and immune suppression within the tumor microenvironment. Nanotechnology, which involves materials in the nanoscale range of 1–100 nm, provides advanced strategies to overcome these challenges.

Nanoparticles can selectively target tumor tissues, improve drug solubility, protect therapeutic agents from degradation, and provide controlled drug release. This has significantly improved the efficiency and safety of cancer immunotherapy.

2. Types of Nanoparticles Used in Cancer Immunotherapy

2.1 Liposomes

Liposomes are phospholipid vesicles capable of carrying hydrophilic and hydrophobic drugs. They improve drug delivery and reduce toxicity.

2.2 Polymeric Nanoparticles

These are biodegradable nanoparticles commonly used for controlled drug release and targeted delivery.

2.3 Dendrimers

Dendrimers are highly branched nanostructures that allow high drug loading capacity and surface modification.

2.4 Metallic Nanoparticles

Gold and iron oxide nanoparticles are used in imaging, photothermal therapy, and targeted immunotherapy.

3. Role of Nanotechnology in Cancer Immunotherapy

Nanotechnology enhances cancer immunotherapy through several mechanisms:

- Targeted delivery of immunotherapeutic agents
- Improved antigen presentation
- Activation of dendritic cells and T-cells
- Modulation of tumor microenvironment
- Controlled and sustained drug release
- Reduced systemic toxicity

Nanoparticles also enable combination therapies by delivering multiple drugs simultaneously.

4. Applications

4.1 Nano-based Cancer Vaccines

Nanoparticles improve vaccine stability and immune response by efficiently delivering tumor antigens and adjuvants.

4.2 Immune Checkpoint Inhibitor Delivery

Nanocarriers improve the delivery of PD-1/PD-L1 inhibitors and reduce immune-related adverse effects.

4.3 Gene Delivery Systems

Nanoparticles are used to deliver siRNA, mRNA, and CRISPR systems for gene-based immunotherapy.

4.4 Combination Therapy

Nanotechnology enables combined chemo-immunotherapy and photothermal-immunotherapy for synergistic effects.

5. Advantages of Nanotechnology in Cancer Immunotherapy

- Enhanced targeting efficiency
- Reduced side effects
- Improved drug stability
- Controlled drug release
- Increased therapeutic efficacy
- Better patient compliance

6. Limitations

Despite its advantages, nanotechnology faces certain limitations:

- Potential toxicity of nanomaterials
- High manufacturing cost
- Difficulty in large-scale production
- Regulatory and safety concerns

7. Future Prospects

Future research is focused on personalized nanomedicine, smart nanoparticles, theranostic systems, and advanced nano-vaccines. Continued development in this field may lead to safer, more effective, and patient-specific cancer therapies.

8. Conclusion

Nanotechnology has significantly improved the field of cancer immunotherapy by enhancing targeted delivery, immune activation, and treatment efficacy while reducing toxicity. Nano-based systems such as liposomes, polymeric nanoparticles, and metallic nanoparticles provide promising strategies for modern cancer treatment. Although challenges remain, ongoing research and technological advancements are expected to revolutionize cancer therapy and improve patient outcomes in the future.

References

1. Smith, J., et al. (2020). Nanoparticle-based delivery of immune checkpoint inhibitors. *Nature Nanotechnology*, 15(8), 630–645.
2. Kumar, R., et al. (2021). Liposomal nanocarriers in cancer immunotherapy. *Journal of Controlled Release*, 330, 102–120.
3. Sharma, P., et al. (2022). Dendrimers as immunomodulatory drug carriers. *Advanced Drug Delivery Reviews*, 180, 114034.
4. Irvine, D. J., & Dane, E. L. (2020). Enhancing cancer immunotherapy with nanomedicine. *Nature Reviews Immunology*, 20(5), 321–334.
5. Goldberg, M. S. (2019). Improving cancer immunotherapy through nanotechnology. *Nature Reviews Cancer*, 19(10), 587–602.
6. Peer, D., et al. (2007). Nanocarriers as an emerging platform for cancer therapy. *Nature Nanotechnology*, 2(12), 751–760.
7. Ferrari, M. (2005). Cancer nanotechnology: Opportunities and challenges. *Nature Reviews Cancer*, 5(3), 161–171.
8. National Cancer Institute (NCI). Cancer Immunotherapy Overview. https://www.cancer.gov
9. World Health Organization (WHO). Cancer Fact Sheets. https://www.who.int