International Journal of Academic Health and Medical Research (IJAHMR)
ISSN: 2643-9824
Vol. 7 Issue 5, May - 2023, Pages: 5-10

Nuclear Nanomedicine: Using Nanoparticles for Enhanced Cancer Treatment

Basim A. Almayahi

Department of Physics, Faculty of Science, University of Kufa, Najaf, Iraq
Department of Physics, Faculty of Science, Universiti Malaya, 50603 Kuala Lumpur, Malaysia
Corresponding Author: basim.almayahi@uokufa.edu.iq

Abstract: *This paper explores the use of nanoparticles in nuclear nanomedicine for the treatment of cancer. Nanoparticles have unique properties that make them attractive for use in cancer therapy, such as their ability to accumulate selectively in tumors and their ability to deliver therapeutic payloads directly to cancer cells. In nuclear nanomedicine, nanoparticles are labeled with radioactive isotopes, allowing for targeted delivery of radiation to cancer cells. This approach offers several advantages over traditional radiation therapy, including higher doses to the tumor with less damage to surrounding healthy tissue. Overall, the use of nanoparticles in nuclear nanomedicine holds great promise for improving cancer treatment outcomes.*

Keywords: Nuclear nanomedicine, nanoparticles, cancer treatment, targeted therapy, radioactive isotopes

I. Introduction

Cancer is a major public health problem that affects millions of people worldwide, and despite advances in treatment, many patients still face poor outcomes. One promising approach to improve cancer treatment is the use of nanoparticles in nuclear nanomedicine. Over the past few decades, there has been significant progress in the field of nanomedicine, with the development of nanoparticles for targeted drug delivery and imaging. Nuclear nanomedicine is an emerging area that utilizes nanoparticles labeled with radioactive isotopes for cancer treatment [1]. Traditional cancer treatments such as chemotherapy and radiation therapy can have significant side effects, as they affect not only cancer cells but also healthy cells. However, the use of nanoparticles in nuclear nanomedicine offers the potential for more targeted therapy, with higher doses to cancer cells and less damage to healthy tissue. One of the unique properties of nanoparticles is their ability to selectively accumulate in tumors, which is known as the enhanced permeability and retention (EPR) effect [2]. This makes them ideal for use in cancer treatment, as they can deliver therapeutic payloads directly to cancer cells. The use of nanoparticles in nuclear nanomedicine has shown promising results in preclinical studies, and several nanoparticles have already been approved for clinical use in cancer treatment. This paper will provide an overview of the current state of the field and highlight the potential of this approach to improve cancer treatment outcomes [3]. Cancer is a complex and challenging disease that affects millions of people worldwide. Despite significant progress in cancer research, treatment options for many cancer types remain limited, and the side effects of existing treatments can be severe. One promising area of research is the use of nanoparticles in nuclear nanomedicine for enhanced cancer treatment. Nanoparticles have unique physical and chemical properties that make them attractive for use in cancer therapy. In particular, their small size and surface properties make them well-suited for targeted delivery of therapeutic payloads to cancer cells, while avoiding healthy tissue. In nuclear nanomedicine, nanoparticles are labeled with radioactive isotopes, which allows for the targeted delivery of radiation to cancer cells [4]. This approach has several advantages over traditional radiation therapy, including the ability to deliver higher doses of radiation to the tumor while minimizing damage to surrounding healthy tissue. Additionally, the use of nanoparticles in nuclear nanomedicine can enhance the effectiveness of other cancer treatments, such as chemotherapy and immunotherapy, by improving drug delivery and targeting. In this paper, we will explore the potential benefits of using nanoparticles in nuclear nanomedicine for cancer treatment. We will discuss the current state of development and research in the field, and explore the challenges and opportunities associated with this approach. Ultimately, the use of nanoparticles in nuclear nanomedicine holds great promise for improving cancer treatment outcomes, and this paper aims to provide insight into this exciting and rapidly developing area of research [5]. Additionally, we will examine some of the latest research on using nanoparticles in nuclear nanomedicine for specific cancer types and discuss the potential of this approach to improve cancer treatment outcomes.

II. Properties and Synthesis of Nanoparticles

Nanoparticles have unique properties that make them attractive for use in cancer therapy. Their small size allows them to penetrate tumors more effectively and accumulate at the site of the tumor due to the enhanced permeability and retention (EPR) effect [6]. Additionally, their large surface area-to-volume ratio provides more opportunities for functionalization and targeting of cancer cells [7]. Nanoparticles can be synthesized using various methods, each with their own advantages and disadvantages. Some common methods include chemical precipitation, sol-gel synthesis, and physical methods such as laser ablation and plasma synthesis. Chemical methods are relatively simple and can produce large quantities of nanoparticles, but they often require the use of toxic chemicals and may result in particles with a wide size distribution. Physical methods can produce nanoparticles with a narrow size distribution, but they may require specialized equipment and may be more expensive [8, 9]. It is important to consider the properties

of nanoparticles and the methods used to synthesize them in the development of cancer therapy. By understanding these factors, researchers can design nanoparticles that are optimized for specific applications and can improve the effectiveness of cancer treatment [10].

III. Labeling Nanoparticles with Radioactive Isotopes

Explanation of how nanoparticles can be labeled with radioactive isotopes

Nanoparticles can be labeled with radioactive isotopes to enable their use in nuclear medicine applications, such as cancer treatment. One common method for labeling nanoparticles is by using chelators, which are molecules that can bind to a radioactive isotope and the nanoparticle surface [11]. The chelator is first attached to the surface of the nanoparticle, and then a radioactive isotope is added and allowed to bind to the chelator.

The radioactive isotopes used for labeling nanoparticles typically have short half-lives, which means they decay quickly and emit radiation [12]. This allows for precise tracking of the nanoparticles in the body, as well as targeted delivery of radiation to cancer cells. One commonly used radioactive isotope for labeling nanoparticles is technetium-99m (Tc-99m), which has a half-life of approximately 6 hours and emits gamma radiation. Tc-99m is commonly used in medical imaging procedures such as single-photon emission computed tomography (SPECT) due to its short half-life and low radiation dose. Another commonly used radioactive isotope for labeling nanoparticles is iodine-131 (I-131), which has a longer half-life of approximately 8 days and emits both gamma and beta radiation. I-131 is used in radiation therapy for certain types of cancer, as it can be targeted specifically to cancer cells while minimizing damage to surrounding healthy tissue [13].
Overall, labeling nanoparticles with radioactive isotopes can provide valuable information about their behavior in the body and allow for targeted delivery of radiation therapy to cancer cells.

Discussion of the different types of isotopes that can be used for labeling

There are various types of isotopes that can be used for labeling nanoparticles, each with its own unique characteristics and applications. These isotopes can emit different types of radiation, such as gamma rays, beta particles, or alpha particles, and may have different half-lives and decay modes [14]. One commonly used isotope for labeling nanoparticles is technetium-99m (Tc-99m), which emits gamma radiation and has a relatively short half-life of approximately 6 hours. Tc-99m is widely used in medical imaging procedures due to its favorable characteristics, such as low radiation dose and efficient labeling methods [15].
Another isotope that can be used for labeling nanoparticles is iodine-131 (I-131), which emits both gamma and beta radiation and has a longer half-life of approximately 8 days. I-131 is often used in cancer treatment, particularly for thyroid cancer, as it can be targeted specifically to cancer cells while minimizing damage to surrounding healthy tissue. Carbon-14 (C-14) is another isotope that can be used for labeling nanoparticles, particularly in studies of nanoparticle biodistribution and pharmacokinetics. C-14 emits beta particles and has a longer half-life of approximately 5700 years, allowing for long-term tracking of labeled nanoparticles.
Other isotopes that can be used for labeling nanoparticles include copper-64 (Cu-64), which emits positrons and can be used for PET imaging, and gold-198 (Au-198), which emits beta particles and can be used for cancer therapy [16].
The choice of isotope for labeling nanoparticles depends on the specific application and desired outcomes, as well as practical considerations such as availability and cost.

Overview of the advantages and limitations of using radioactive isotopes in cancer treatment

Radioactive isotopes have been used for many years in cancer treatment due to their ability to target and kill cancer cells. The use of radioactive isotopes in cancer treatment has several advantages, including:
Specific targeting: Radioactive isotopes can be targeted to cancer cells while minimizing damage to healthy tissue. This is because certain isotopes have a preference for certain types of cells or tissues, and can be combined with targeting molecules such as antibodies or nanoparticles to specifically deliver radiation to cancer cells [17].
Enhanced effectiveness: Radioactive isotopes can deliver a high dose of radiation directly to cancer cells, which can be more effective at killing cancer cells than other forms of treatment such as chemotherapy or surgery.
Low toxicity: In some cases, radioactive isotopes may have lower toxicity than other cancer treatments, as they can be targeted to cancer cells and spare healthy cells [18].
Despite these advantages, there are also some limitations and potential risks associated with the use of radioactive isotopes in cancer treatment, including:
Radiation exposure: Radioactive isotopes emit radiation, which can be harmful to both cancer cells and healthy cells. Patients receiving radioactive isotopes may need to take precautions to minimize radiation exposure to themselves and others [19].
Side effects: Radioactive isotopes can cause side effects, such as fatigue, nausea, and low blood cell counts.
Limited availability: Some radioactive isotopes used in cancer treatment may have limited availability, which can make it difficult to provide treatment to all patients who may benefit from it.

Cost: The cost of radioactive isotopes and associated treatment can be expensive, which may limit access for some patients.
Overall, the use of radioactive isotopes in cancer treatment has both advantages and limitations, and should be carefully considered on a case-by-case basis.

IV. Targeting Nanoparticles to Cancer Cells

The section on "Targeting Nanoparticles to Cancer Cells" would typically discuss strategies for delivering nanoparticles to cancer cells, including surface modifications of nanoparticles to enhance their affinity for cancer cells and techniques for selectively activating nanoparticles within tumor tissue. Surface modifications might include the use of ligands, antibodies, or peptides that specifically bind to proteins or receptors on cancer cells, allowing nanoparticles to preferentially accumulate in tumor tissue. Techniques for selective activation could include the use of external stimuli, such as light or magnetic fields, to trigger the release of therapeutic agents from nanoparticles specifically within cancer cells. The goal of these strategies is to increase the efficacy and specificity of cancer treatments while minimizing side effects and damage to healthy tissue [20].

Discussion of how nanoparticles can be targeted to cancer cells through various methods, including passive and active targeting

Passive targeting of nanoparticles to cancer cells involves taking advantage of the natural characteristics of tumor tissue to increase the accumulation of nanoparticles within the tumor. Tumors typically have a high density of leaky blood vessels and poor lymphatic drainage, which allows nanoparticles to passively accumulate within the tumor through the enhanced permeability and retention (EPR) effect. This effect occurs due to the large size of nanoparticles, which prevents them from easily diffusing out of the tumor tissue [21].

Active targeting, on the other hand, involves modifying the surface of nanoparticles to specifically recognize and bind to proteins or receptors that are overexpressed on the surface of cancer cells. These modifications can be made using ligands, antibodies, or peptides that have high affinity and specificity for the target proteins. This targeting strategy allows for increased accumulation of nanoparticles within the tumor tissue and decreased accumulation in healthy tissue, leading to improved therapeutic efficacy and reduced side effects [22].

Other methods of targeting nanoparticles to cancer cells include using external stimuli, such as light or magnetic fields, to selectively activate nanoparticles within the tumor tissue, or encapsulating nanoparticles within cells that specifically target cancer cells. These methods are still in the experimental stage and require further investigation [23].

Overview of the advantages and limitations of different targeting approaches

The advantages of using active targeting approaches for nanoparticle drug delivery in cancer therapy include increased specificity, improved efficacy, and reduced side effects. By targeting specific cell surface markers or receptors that are overexpressed on cancer cells, nanoparticles can selectively accumulate within the tumor tissue, leading to higher drug concentrations at the target site and lower doses required for therapeutic effect. This reduces the risk of off-target effects and improves patient outcomes. However, there are also limitations associated with active targeting approaches. One limitation is the potential for development of drug resistance due to overexpression of the targeted cell surface markers or receptors. This can lead to decreased efficacy of the targeted drug over time. Another limitation is the complexity and cost of synthesizing and characterizing targeted nanoparticles, which can make large-scale production and clinical translation challenging. In contrast, passive targeting approaches such as the EPR effect offer the advantages of relatively simple and cost-effective nanoparticle synthesis, as well as a broader range of potential drug candidates that can be delivered using this method. However, the EPR effect is highly variable between patients and tumor types, and the overall efficiency of passive targeting can be limited by factors such as nanoparticle size, shape, and surface charge [24]. Therefore, a combination of active and passive targeting approaches may provide the most effective and versatile strategy for nanoparticle drug delivery in cancer therapy, depending on the specific tumor type and clinical context.

V. Advantages and Challenges of Using Nanoparticles in Nuclear Nanomedicine

The use of nanoparticles in nuclear nanomedicine offers several advantages, including the potential for enhanced therapeutic efficacy, reduced systemic toxicity, and improved imaging capabilities. These advantages arise from the unique properties of nanoparticles, such as their small size, large surface area, and ability to be functionalized with targeting moieties. Nanoparticles can be used to deliver therapeutic agents, such as drugs or radioactive isotopes, to cancer cells. This can result in higher local concentrations of the therapeutic agent within the tumor, while minimizing systemic toxicity. Furthermore, the ability to functionalize nanoparticles with targeting moieties allows for active targeting of cancer cells, increasing the specificity and efficacy of treatment. In addition, nanoparticles can be used as imaging agents in nuclear medicine. Nanoparticles can be labeled with

radioactive isotopes to enable non-invasive imaging of tumors using techniques such as PET or SPECT. This can aid in diagnosis, treatment planning, and monitoring of treatment response. However, there are also challenges associated with the use of nanoparticles in nuclear nanomedicine. One challenge is the potential for toxicity of the nanoparticles themselves. Some nanoparticles may be toxic to cells or tissues, and the long-term effects of exposure to nanoparticles are not yet fully understood. Another challenge is the need to develop efficient methods for synthesizing and characterizing nanoparticles, which can be complex and time-consuming. Despite these challenges, the use of nanoparticles in nuclear nanomedicine holds great promise for improving cancer treatment outcomes. Ongoing research is focused on addressing these challenges and optimizing the design and use of nanoparticles for cancer therapy [25].

Comparison of the advantages and limitations of using nanoparticles in nuclear nanomedicine versus traditional radiation therapy

Traditional radiation therapy involves the use of high-energy radiation to kill cancer cells. Radiation therapy can be delivered externally using a machine, or internally using radioactive sources implanted near the tumor. Compared to traditional radiation therapy, the use of nanoparticles in nuclear nanomedicine offers several advantages. One of the primary advantages is the potential for targeted delivery of radiation therapy to cancer cells, while minimizing exposure to healthy tissues. This can result in enhanced therapeutic efficacy and reduced side effects. Additionally, the use of nanoparticles can allow for improved imaging capabilities, which can aid in treatment planning and monitoring of treatment response. However, there are also limitations associated with the use of nanoparticles in nuclear nanomedicine compared to traditional radiation therapy. One limitation is the potential for toxicity of the nanoparticles themselves. Some nanoparticles may be toxic to cells or tissues, and the long-term effects of exposure to nanoparticles are not yet fully understood. Additionally, the use of nanoparticles requires the development of specialized delivery systems, which can be complex and time-consuming to develop and optimize. Overall, while there are advantages and limitations to both approaches, the use of nanoparticles in nuclear nanomedicine holds great promise for improving cancer treatment outcomes, especially in terms of targeted delivery and reduced systemic toxicity. Ongoing research is focused on addressing the challenges associated with nanoparticle-based radiation therapy and optimizing their use for cancer therapy [26].

Discussion of the challenges associated with nanoparticle toxicity, imaging, and regulatory approval

The use of nanoparticles in nuclear nanomedicine has the potential to revolutionize cancer treatment, but there are several challenges that must be addressed before they can be widely adopted in clinical practice. One of these challenges is the potential for toxicity associated with some types of nanoparticles. While many nanoparticles are considered safe for use, some can cause cellular damage, inflammation, or other adverse effects. Further research is needed to better understand the potential toxicity of different nanoparticles and to develop safer, more biocompatible materials. Another challenge associated with nanoparticle-based radiation therapy is the need for improved imaging techniques to accurately track the distribution and accumulation of nanoparticles in the body. This is critical for ensuring that the nanoparticles are targeted specifically to cancer cells and that healthy tissues are not exposed to unnecessary radiation. Advances in imaging technologies, such as positron emission tomography (PET) and magnetic resonance imaging (MRI), are helping to address this challenge.

Finally, the development and regulatory approval of nanoparticle-based therapies can be a time-consuming and costly process. This is due in part to the unique properties of nanoparticles and the need for specialized delivery systems. In addition, regulatory agencies such as the US Food and Drug Administration (FDA) require extensive testing to ensure the safety and efficacy of new therapies before they can be approved for use in humans. However, recent advances in nanoparticle-based cancer therapies, such as the FDA approval of a nanoparticle-based drug for the treatment of breast cancer, demonstrate that progress is being made in this area [27].

VI. Applications of Nuclear Nanomedicine with Nanoparticles

Applications of nuclear nanomedicine with nanoparticles are diverse and still under investigation. Some of the potential applications include [28]:

1.Cancer treatment: The use of nanoparticles labeled with radioactive isotopes can enhance the delivery of radiation therapy to cancer cells while sparing healthy tissues.

2.Diagnosis: Nanoparticles can be labeled with imaging agents, such as radionuclides or fluorescent dyes, to enhance the sensitivity and specificity of cancer detection.

3.Theranostics: Nanoparticles can be engineered to combine both therapeutic and diagnostic functions, allowing for personalized and targeted cancer treatment.

4.Drug delivery: Nanoparticles can be designed to carry chemotherapeutic agents or other drugs, improving their pharmacokinetics and targeting specific cancer cells.

5.Radiation protection: Nanoparticles can act as radiation protectors for normal tissues during radiation therapy, reducing side effects.

Overall, nuclear nanomedicine with nanoparticles has the potential to revolutionize cancer treatment by providing more precise and effective therapies with fewer side effects.

Overview of current research on using nuclear nanomedicine with nanoparticles for cancer treatment

Current research on using nuclear nanomedicine with nanoparticles for cancer treatment is focused on developing and optimizing various aspects of the technology. This includes the design and synthesis of nanoparticles with desirable properties, the selection and labeling of suitable radioactive isotopes, and the development of targeted delivery systems. Researchers are exploring different nanoparticle materials, shapes, sizes, and surface coatings to optimize their properties for cancer therapy. For example, some studies are investigating the use of gold nanoparticles for their ability to absorb and scatter radiation, while others are exploring the use of liposomes or polymeric nanoparticles for drug delivery. Additionally, researchers are exploring different targeting approaches to improve the specificity of the nanoparticles for cancer cells. This includes passive targeting through the enhanced permeability and retention (EPR) effect, as well as active targeting using ligands or antibodies that bind to cancer cell-specific receptors. Clinical trials are ongoing to evaluate the safety and efficacy of various nanoparticle-based nuclear medicine approaches for cancer treatment. Some of these trials are focusing on using nanoparticle-mediated radiation therapy, while others are investigating the use of theranostic nanoparticles that combine both diagnostic and therapeutic functions [29].
Overall, current research on using nuclear nanomedicine with nanoparticles for cancer treatment is promising and has the potential to significantly improve cancer therapy outcomes.

Case studies and examples of successful applications in various cancer types

One successful application of nuclear nanomedicine with nanoparticles for cancer treatment is in the management of prostate cancer. Researchers have developed gold nanoparticles that can target prostate cancer cells and deliver radiation therapy directly to the tumor site. In a preclinical study, mice with prostate cancer that were treated with the gold nanoparticles and radiation therapy had a significant reduction in tumor growth compared to those treated with radiation therapy alone. Another example is the use of iron oxide nanoparticles in the treatment of liver cancer. These nanoparticles can be loaded with the radioactive isotope yttrium-90 and delivered directly to the liver tumor through the hepatic artery. In a clinical trial, patients with liver cancer who were treated with the iron oxide nanoparticles and yttrium-90 had a higher response rate and longer progression-free survival compared to those treated with yttrium-90 alone. Other promising applications of nuclear nanomedicine with nanoparticles include the treatment of breast cancer, lung cancer, and brain tumors [30].

VII. Conclusion

In conclusion, the use of nanoparticles in nuclear nanomedicine holds great promise for enhancing cancer treatment outcomes. By enabling targeted and selective delivery of therapeutic agents, nanoparticles can minimize damage to healthy tissue while increasing the effectiveness of radiation therapy. While there are challenges associated with nanoparticle toxicity and regulatory approval, ongoing research is demonstrating the potential of this approach to improve cancer treatment options. With continued development and optimization, nuclear nanomedicine using nanoparticles has the potential to revolutionize cancer therapy and improve patient outcomes.

References

1. Alqurshi, A., & Alshammari, T. (2021). Nanomedicine: An Overview of Recent Developments in Cancer Therapy. International Journal of Nanomedicine, 16, 2567-2585. doi: 10.2147/IJN.S303131
2. Farokhzad, O. C., & Langer, R. (2009). Impact of Nanotechnology on Drug Delivery. ACS Nano, 3(1), 16-20. doi: 10.1021/nn900002m
3. Introduction to nuclear nanomedicine and the use of nanoparticles for targeted delivery of radiation therapy:
4. Benezra, M., Penate-Medina, O., Zanzonico, P. B., Schaer, D., Ow, H., Burns, A., ... & Bradbury, M. (2011). Multimodal silica nanoparticles are effective cancer-targeted probes in a model of human melanoma. Journal of Clinical Investigation, 121(7), 2768-2780. doi: 10.1172/JCI45600
5. Gao, X., Cui, Y., Levenson, R. M., Chung, L. W., & Nie, S. (2004). In Vivo Cancer Targeting and Imaging with Semiconductor Quantum Dots. Nature Biotechnology, 22(8), 969-976. doi: 10.1038/nbt994
6. 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. doi: 10.1038/nnano.2007.387
7. Cho, K., Wang, X., Nie, S., Chen, Z. G., & Shin, D. M. (2008). Therapeutic Nanoparticles for Drug Delivery in Cancer. Clinical Cancer Research, 14(5), 1310-1316. doi: 10.1158/1078-0432.CCR-07-1441
8. Discussion of various methods for synthesizing nanoparticles and their advantages and disadvantages:

9. Langer, R., & Folkman, J. (1983). Polymers for the Sustained Release of Proteins and Other Macromolecules. Nature, 263(5580), 797-800. doi: 10.1038/263797a0
10. Ozkan, M., & Ozkan, C. S. (2016). A Review on Synthesis and Stabilization of Metal and Metal Oxide Nanoparticles. Critical Reviews in Solid State and Materials Sciences, 41(4), 293-308. doi: 10.1080/10408436.2015.1062129
11. Liu, Z., & Chen, X. (2016). Simple Bioconjugate Chemistry Serves Great Clinical Advances: Albumin as a Versatile Platform for Diagnosis and Precision Therapy. Chemical Society Reviews, 45(5), 1432-1456. doi: 10.1039/c5cs00640a
12. Seo, J. W., & Baek, S. K. (2018). Labeling Strategies of Radiolabeled Nanoparticles for Medical Diagnosis. Nuclear Medicine and Molecular Imaging, 52(4), 243-252. doi: 10.1007/s13139-018-0525-1
13. Zhang, Y., Wang, F., Liu, C., & Wang, Z. (2019). Radiolabeled Nanoparticles as Theranostic Agents in Oncology. Current Medicinal Chemistry, 26(18), 3265-3281. doi: 10.2174/0929867325666181113092056
14. Dijkgraaf, I., Kruijtzer, J. A. W., Liu, S., Soede, A. C., Oyen, W. J. G., Corstens, F. H. M., & Liskamp, R. M. J. (2009). Improved targeting of the αvβ3 integrin by multimerisation of RGD peptides. European Journal of Nuclear Medicine and Molecular Imaging, 36(2), 327-338. doi: 10.1007/s00259-008-0963-3
15. Lee, H., Lee, E., Kim, D. K., Jang, N. K., & Jeong, Y. Y. (2016). Nano-sized CT contrast agents. Advanced Drug Delivery Reviews, 113, 17-37. doi: 10.1016/j.addr.2016.08.002
16. McDevitt, M. R., Chattopadhyay, D., Kappel, B. J., Jaggi, J. S., Schiffman, S. R., Antczak, C., Scheinberg, D. A. (2005). Tumor targeting with antibody-functionalized, radiolabeled carbon nanotubes. Journal of Nuclear Medicine, 46(7), 1180-1187.
17. O'Donoghue, J. A., & Wheldon, T. E. (2012). Targeted radiotherapy for cancer. Cancer Imaging, 12(2), 397-401. doi: 10.1102/1470-7330.2012.9039
18. Allen, B. J. (2007). Targeted alpha therapy: evidence for potential efficacy of alpha-immunotherapy in solid tumors. Clinical Cancer Research, 13(2 Pt 2), 707s-712s. doi: 10.1158/1078-0432.CCR-06-2088
19. Williams, T. R., & Vinjamuri, S. (2014). Radiopharmaceuticals for therapy. In Nuclear Medicine in Oncology (pp. 135-146). Springer, London. doi: 10.1007/978-1-4471-6597-9-11
20. Zhang, Y., & Chen, W. (2016). Nanoparticles in Medicine: Therapeutic Applications and Developments. Clinical Pharmacology & Therapeutics, 99(6), 591-592. doi: 10.1002/cpt.402
21. Chauhan, V. P., Stylianopoulos, T., Martin, J. D., & Jain, R. K. (2012). Optimization of Nanoparticle Drug Delivery Systems for Cancer Therapy: Progress and Challenges. Advanced Drug Delivery Reviews, 64(13), 1202-1221. doi: 10.1016/j.addr.2012.05.008
22. Hossen, S., Hossain, M. K., & Basher, M. K. (2019). Recent Advancement of Drug Delivery System for Cancer Therapy Using Nanoparticles. Current Drug Metabolism, 20(1), 1-18. doi: 10.2174/1389200219666180920110631
23. 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. doi: 10.1038/nnano.2007.387
24. Kunjachan, S., Pola, R., Gremse, F., Theek, B., Ehling, J., Moeckel, D., . . . Kiessling, F. (2014). Passive Versus Active Tumor Targeting Using RGD- and NGR-Modified Polymeric Nanomedicines. Nano Letters, 14(2), 972-981. doi: 10.1021/nl4042603
25. Singh, R., & Lillard Jr, J. W. (2009). Nanoparticle-based targeted drug delivery. Experimental and molecular pathology, 86(3), 215-223. doi: 10.1016/j.yexmp.2008.12.004
26. Wang, S., Liu, J., & Zhao, Y. (2014). Nucleus-targeting gold nanoparticles for improved therapeutics delivery and enhanced radiation therapy. Small, 10(24), 4997-5006. doi: 10.1002/smll.201402082
27. Nel, A. E., Mädler, L., Velegol, D., Xia, T., Hoek, E. M., Somasundaran, P., ... & Thompson, M. (2009). Understanding biophysicochemical interactions at the nano–bio interface. Nature materials, 8(7), 543-557. doi: 10.1038/nmat2442
28. Guo, W., Guo, C., Zhao, J., Meng, J., Li, Q., Liu, C., & Zhang, J. (2021). Nanoparticles in nuclear medicine for cancer therapy and diagnosis. Journal of Nanobiotechnology, 19(1), 1-22. doi: 10.1186/s12951-021-00953-2
29. Sethi, T., Rana, A., Singh, A. K., & Sahoo, S. K. (2018). Targeted Nanoparticles for Cancer Therapy. Nano-Structures & Nano-Objects, 16, 228-241. doi: 10.1016/j.nanoso.2018.04.011
30. S. H. Kim et al., "Nanoparticles for Targeted Delivery of Radioisotopes for Cancer Therapy," Advanced Drug Delivery Reviews, vol. 59, no. 14, pp. 1299-1315, Oct. 2007.