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The Impact of Using Nanotechnology in the Early Detection and Diagnosis of Cancer

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Abstract:

The purpose of this article has been to explore the impact of using nanotechnology in the early detection and diagnosis of cancer. This article has examined tools like nanoparticles, quantum dots, and nano-biosensors, which offer precise and early detection of cancer biomarkers even at ultra-low concentrations. The key findings of the article have highlighted that improved diagnostic accuracy and patient outcomes can be achieved through the implementation of nanotechnology. The key benefits involve high sensitivity, target detection and reduced invasiveness, while challenges involve high cost and lack of accessibility. Overall, nanotechnology offers a promising future in oncology diagnostics, thus providing scope for future research in this domain.

Keywords: Nanotechnology, early detection, cancer diagnosis, nanoparticles, biomarkers, oncology, nano bio-sensors

1. Introduction

1.1 The problem of late cancer diagnosis

Cancer is a type of disease in which cells in some parts of the body start to grow uncontrollably and spread to other parts of the body (National Cancer Institute, 2021). Cancer cells ignore cell signalling pathways, unlike normal cells and keep on growing.

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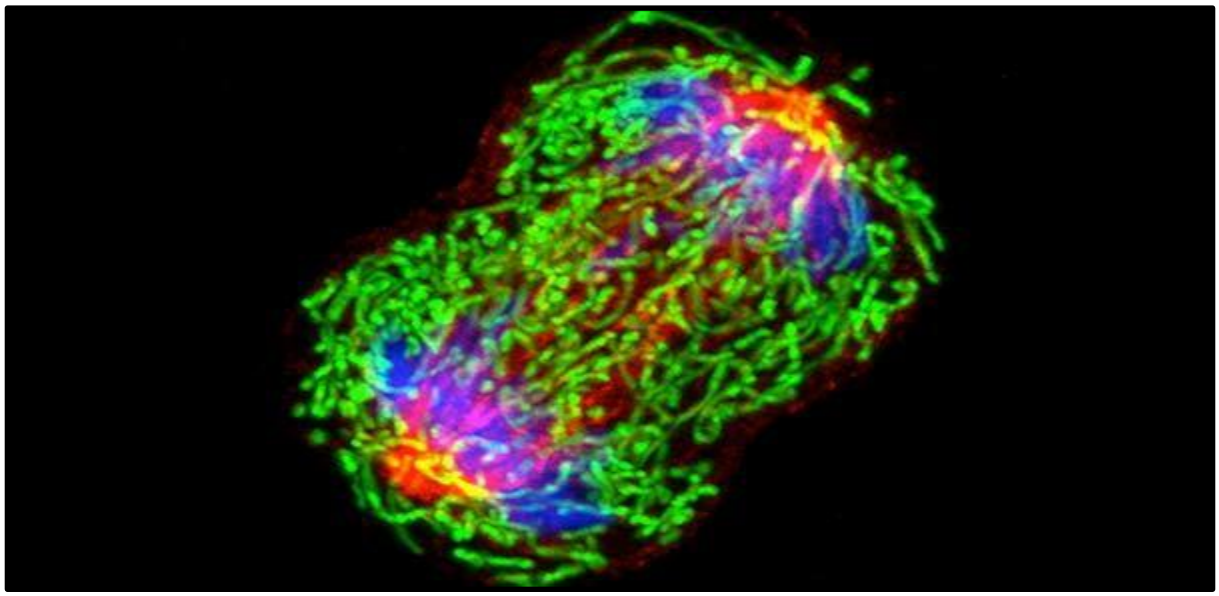

Figure 1: A dividing breast cancer cell

(Source: National Cancer Institute, 2021)

Cancer is caused by certain changes in the genes, which are the basic physical unit of inheritance and are arranged in long strands of DNA called chromosomes, as seen in Figure 2.

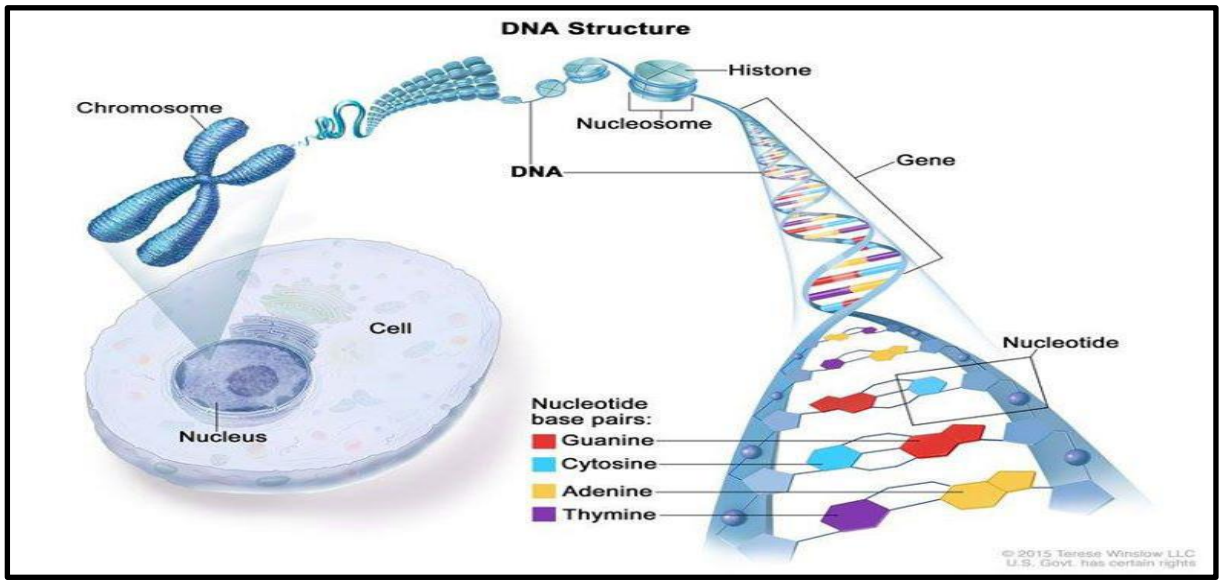

Figure 2: Genes in DNA Strands

(Source: National Cancer Institute, 2021)

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If cancer is caused in the body, then it can lead to issues like pain, fatigue, difficulties, nausea and digestive issues and in most cases, it leads to death due to metastasis (Mayo Clinic, 2025). Once the cancer cells have started metastasising, then even after therapy and treatment, it may return (Cancer Research UK, 2023). Delay in the process of cancer diagnosis leads to higher risk of mortality, shortened lifespan, increased risk of metastasis and decreased effectiveness of treatments. (Mills *et al.* 2023). Therefore, it is vital that cancer is diagnosed at an early stage to ensure effective treatments and care.

1.2 The importance of early detection

According to the World Health Organisation, early detection of cancer generally increases the chances of successful treatments by focusing on identifying symptomatic patients as early as possible (WHO, 2025a). The detection at an early stage can prevent or delay metastasis and improve the outcome of the patients by improving treatment outcomes. Cancer is the leading cause of global death, and in 2022, cancer accounted for 10 million deaths (WHO, 2025b). More than 50% of cancers are at an advanced stage when diagnosed, and therefore, early detection can prevent cancer development and lethality (Crosby *et al.* 2022).

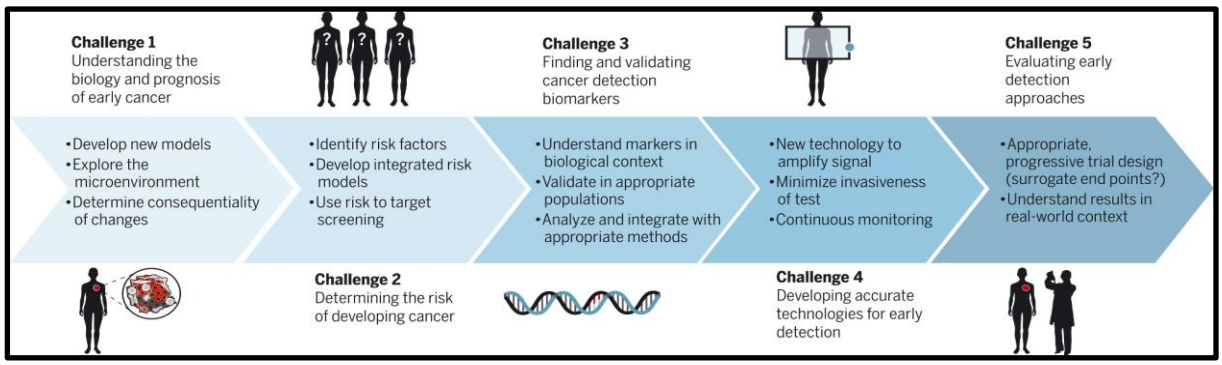

Figure 3: Challenges and mitigation strategies associated with the early detection of cancer

(Source: Crosby *et al.* 2022)

1.3 How nanotechnology offers new possibilities

In the early detection of cancer, nanotechnology has shown significant promise and success rates. Technology makes use of nanoparticles and nano-devices, which are typically one hundred to ten thousand times smaller than a human cell, and are used by researchers to develop diagnostic devices for detecting cancer (National Cancer Institute, 2023).

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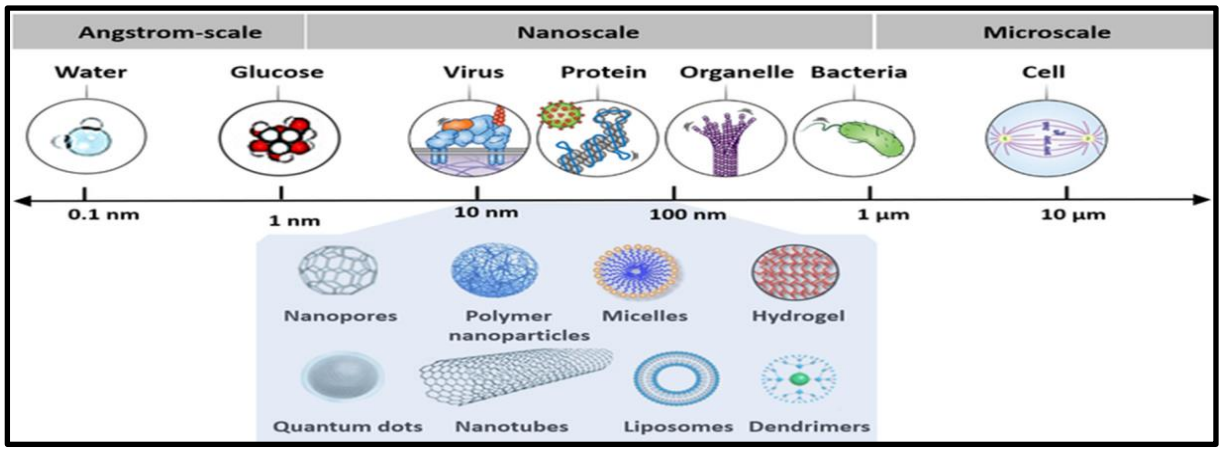

Figure 4: Comparison of the size of nanoparticle devices to other organic cells or molecules

(Source: National Cancer Institute, 2025)

In case of cancer, nanotechnology helps in early detection, diagnosis and therapy by combining a small size and unique properties of nanoparticles, and no device enables precise monitoring of patient response to that and improving patient care. Therefore, Nanotechnology offers new possibilities in cancer detection by enabling earlier and more accurate diagnosis through the process of enhanced imaging, development of highly sensitive biosensors and targeted drug delivery.

1.4 Brief overview of what will be covered in the paper

In this paper, an introduction to the study context is provided, and in section 2, a literature review of past studies is conducted to deepen the knowledge regarding the impact of using technology in the early detection and diagnosis of cancer. After this, an overview of the research method used for collecting data for this research study has been presented, and then the results and discussion on the collected data have been presented. This has been followed by concluding the research findings, and recommendations for future research have also been provided.

2. Literature Review

2.1 Nanotechnology in Cancer Diagnosis

Factors like the effect of cell selectivity and toxicity of traditional chemotherapies remain a significant challenge in cancer detection and treatments (Dessale *et al.* 2022). These limitations entail the need for the development of both safe and effective cancer diagnostics and

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treatments, and nanotechnology, due to its robust applications, could act as a promising method for in vivo imaging and detection of cancer cells as well as cancer biomarkers (Dessale *et al.* 2022).

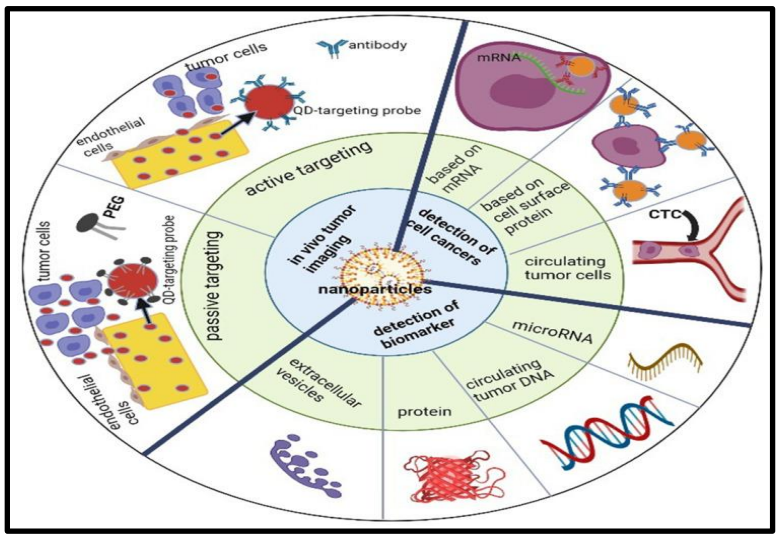

Figure 5: Nanotechnology-based cancer diagnosis

(Source: Dessale *et al.* 2022)

Nanoparticles are used in the treatment and diagnosis of cancer because of their precise ability to detect a single cancer cell and then target it for delivering a payload for the treatment of that cancerous cell (Nasir *et al.* 2021; Gogoi *et al.* 2022). Polymeric nanoparticles, metallic nanoparticles and quantum dots have revolutionised the process of cancer diagnoses and treatment due to their high surface charge, size and morphology

2.2 Biomarkers and Nanosensors

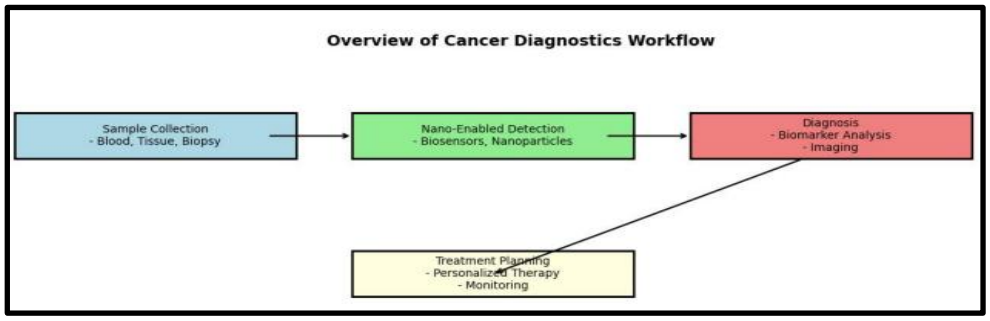

Figure 6: Process of cancer diagnosis using nanotechnology

(Source: Salaudeen and Akinniranye, 2024)

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Precision nanotechnology is used for early cancer detection and identification of cancer biomarkers with the help of unmatched sensitivity and specificity (Salaudeen and Akinniranye, 2024). Nono-biosensors, quantum dots and nanoprobes help in enabling this key invitation because these three nanotechnologies operate at the molecular level and enable the detection of cancer biomarkers even in ultra-low concentrations, which traditional methods fail to identify (Salaudeen and Akinniranye, 2024; Eissa, 2024). The nanobiosensors combine biological recognition elements with nanoparticles, which allows them to provide rapid signal transduction and high sensitivity. Nano probes provide enhanced levels of imaging and targeting capabilities, which enable visualisation of cancerous tissues with unparalleled levels of precision. Quantum dots have unique optical properties which enable multiplexed cancer biomarker detection and real-time imaging (Combes *et al.* 2021). Nanotechnology acts as a non-invasive method of detecting tumour markers and also allows easy sample collection and easy dynamic detection (Den *et al.* 2022).

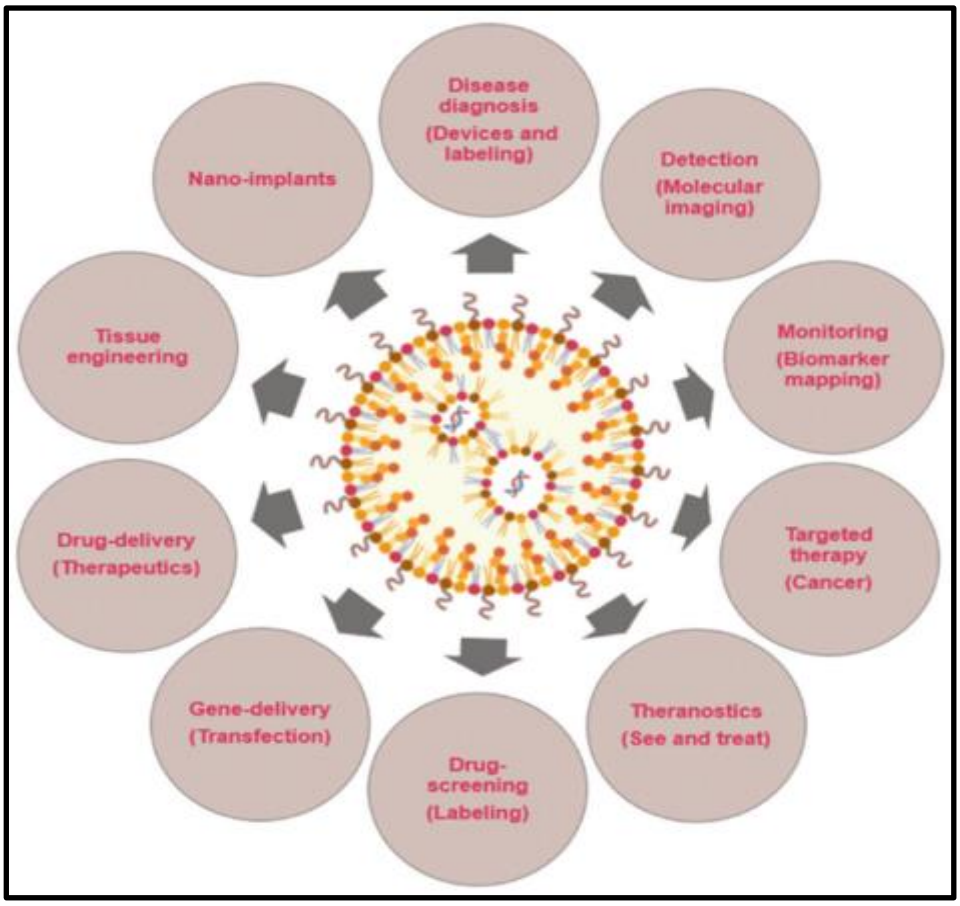

Figure 7: Various fields of nanotechnology operations

(Source: Salaudeen and Akinniranye, 2024)

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2.3 Quantum Dots and Imaging

Quantum dots are made from extremely small metal particles, which are about a thousand times smaller than a hair, and they have a higher potential to degrade than conventional optical imaging tests, which allows them to treat all types of cell measurements for a longer time (Devi *et al.* 2022). QD are nanoclusters and they provide excellent contrast when used in imaging with an electron magnifying lens, when dispersion is improved.QDs are mainly used for improving fluorescent imaging and because of their photochemical stability. They are effective for studying transport mechanisms in cells, understanding the functional heterogeneity of cells and diffusion movements through cell structures.

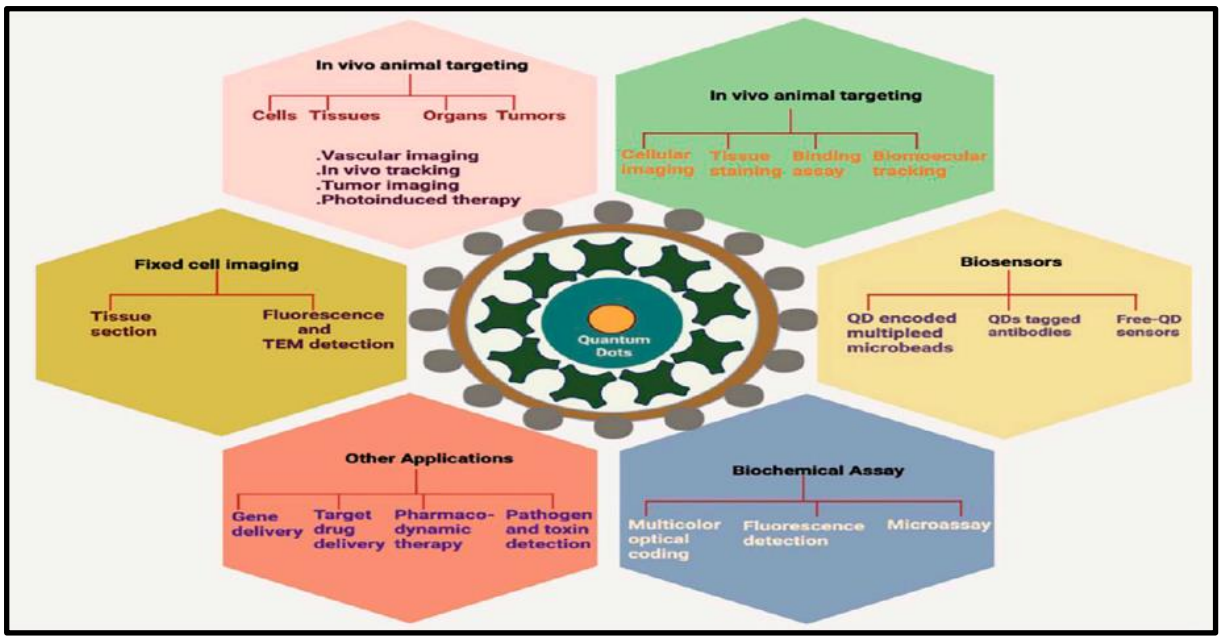

Figure 8: Role of Quantum dots in bioimaging

(Source: Devi *et al.* 2022)

QDs have grabbed significant interest in the field of cancer detection due to their excellent photostability, bright fluorescence, good electrical and chemical stability and high biocompatibility with minimal invasiveness (Naik *et al.* 2022). As a result, oncologists are offering carbon QDs rather than organic QDs to facilitate the process of bioimaging, drug delivery, and biosensing.

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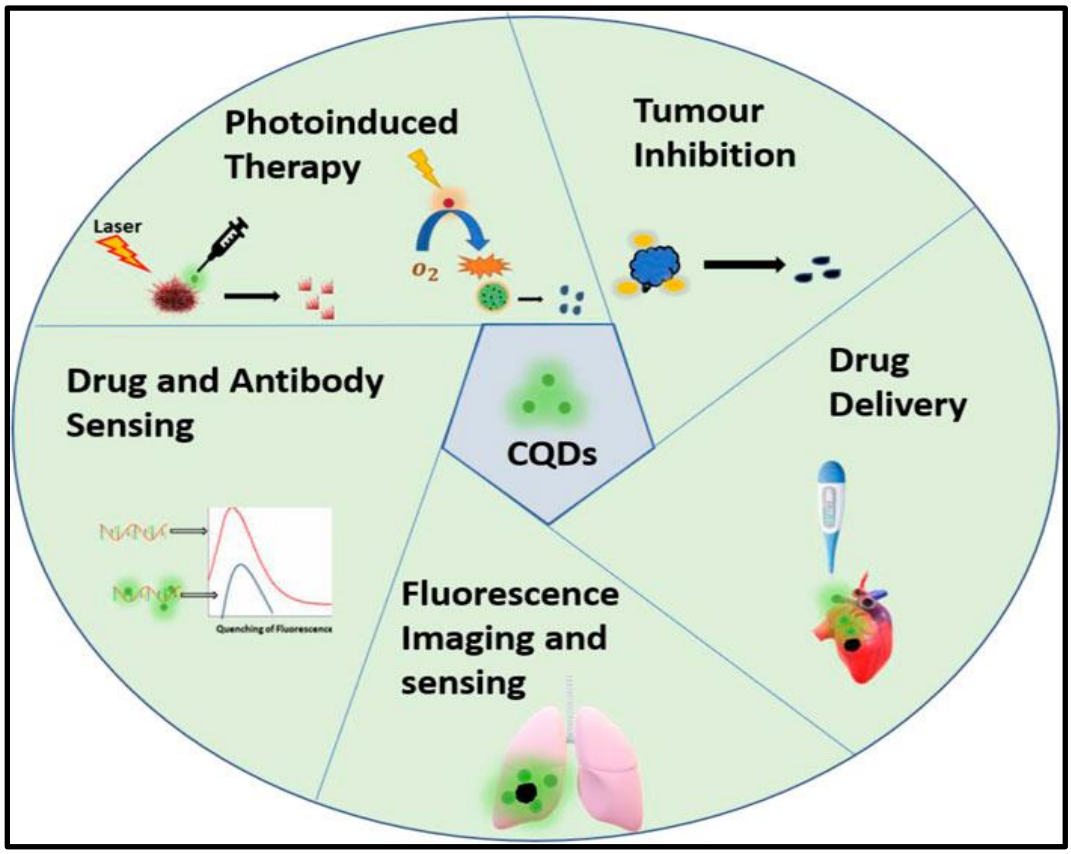

Figure 9: Application of carbon quantum dots in cancer diagnosis

(Source: Naik *et al.* 2022)

2.4 Comparative Studies

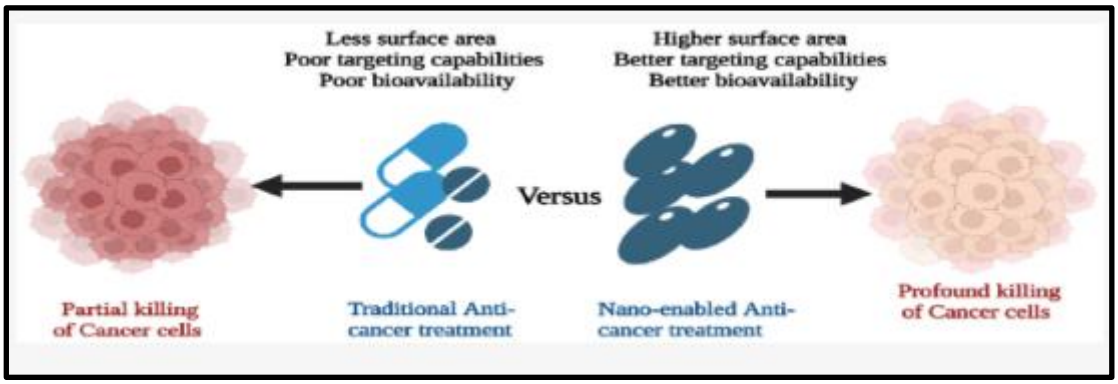

Figure 10: Comparison of traditional and nano-based methods of cancer treatment

(Source: Alrushaid *et al.* 2023)

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Traditional cancer diagnosis has been aided by the application of nanoparticles, which has made the process of cancer diagnosis faster and easier (Alrushaid *et al.* 2023). Nanoparticles possess exceptional properties such as larger surface areas, higher volume proportion, and better targeting capabilities (Alrushaid *et al.* 2023).

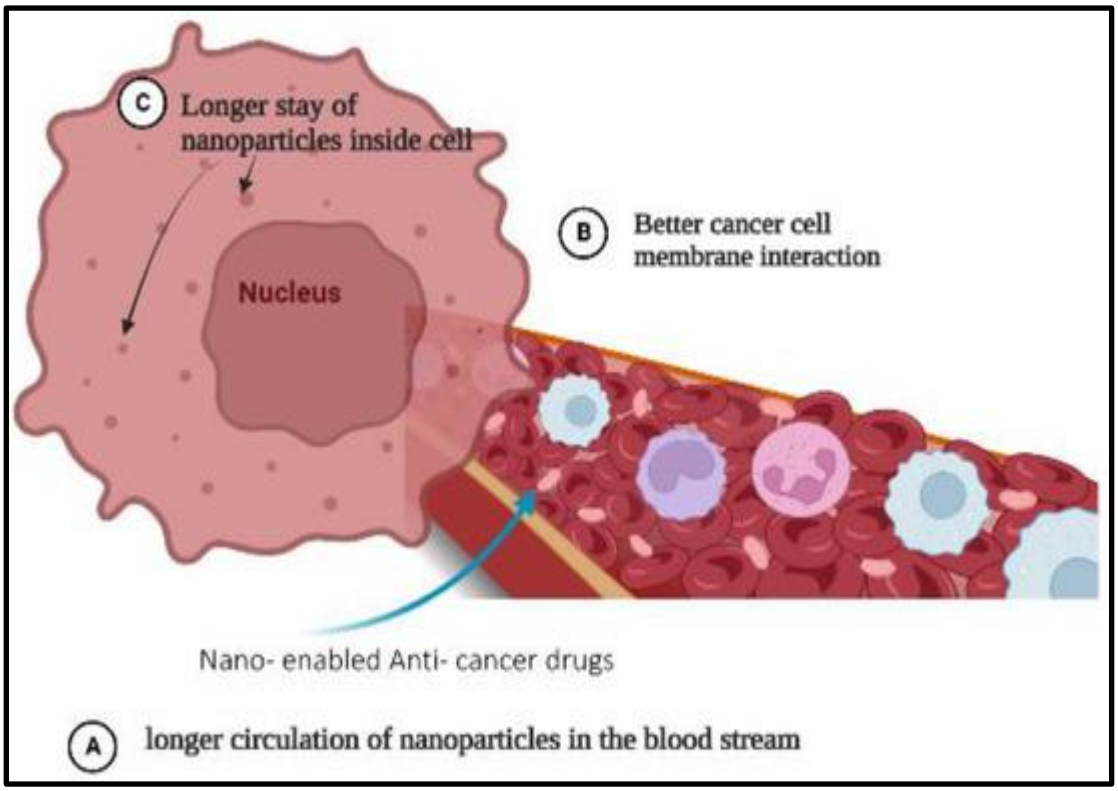

Figure 11: Entry and movements of nano-enabled anticancer drugs in cancer cells

(Source: Alrushaid *et al.* 2023)

Cancer detection and treatments are increasingly involving the use of nanotechnology because of their increasing specificity and decreased levels of systemic toxicities, unlike traditional diagnostic methods (Kemp and Kwon, 2021). In addition to this, traditional cancer detection methods consist of high radiation doses, and a lack of specific targeting often makes them ineffective and can also delay the decision. Therefore, even though the use of nanotechnology is limited, they are still being increasingly considered for early detection and precise targeting of cancer cells in diagnosis and to improve patient quality of life.

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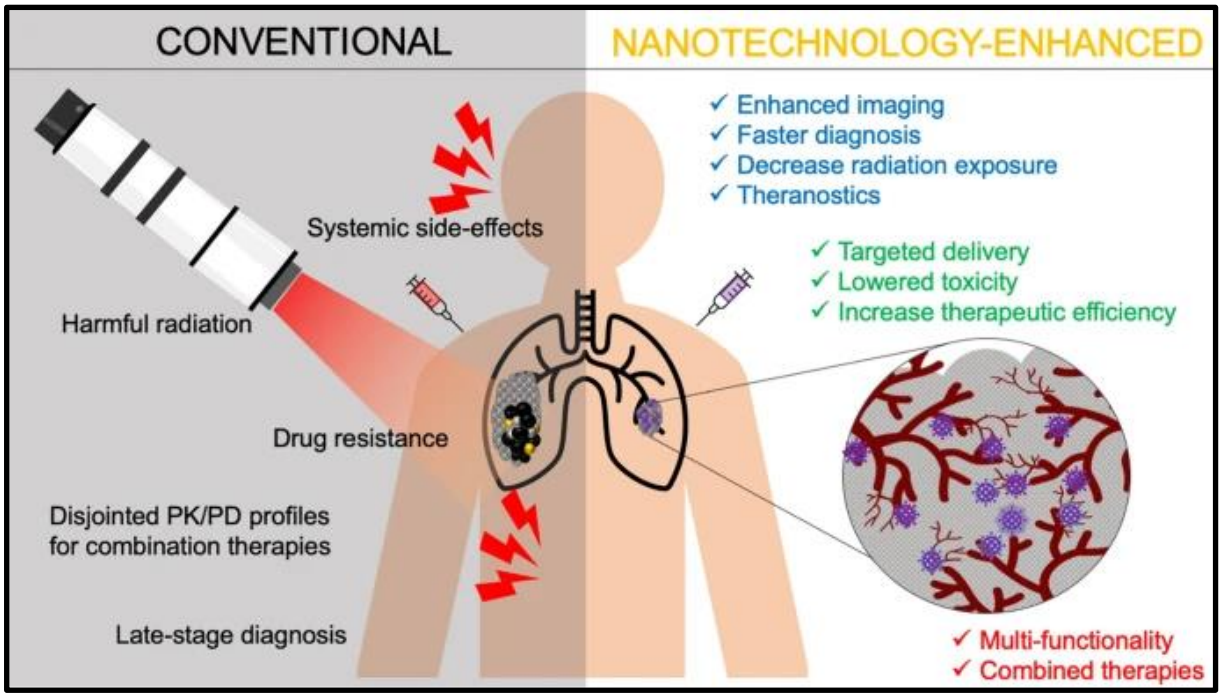

Figure 12: Conventional cancer therapy versus nanotechnology-enhanced

(Source: Kemp and Kwon, 2021)

Summary of Literature

Thus, from the literature, it can be summarised that the use of nanoparticles in cancer detection is being increasingly preferred due to their increasing specificity and ability to target even a single cancer cell precisely. Nanoparticles have reduced toxicity, and the use of quantum dots helps in enriching cancer detection through fluorescent imaging.

3. Research Method

3.1 Research design

This present study employs a qualitative research method in which an open-ended semi-structured interview with two cancer specialists will be conducted to understand the impact of using nanotechnology in the early detection and diagnosis of cancer. Interviews act as an effective method for developing a deeper understanding of the lived experience of research participants regarding the research phenomenon (Husband, 2020). This methodology has been chosen because, from the literature review, it has been observed that there is a lack of studies exploring the perspectives of cancer specialists regarding the benefit of using nanotechnology in early detection and diagnosis of cancer.

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3.2 Participants

The participants will be two cancer specialists (oncologists) with at least 5 years of experience in the field of cancer. A purposive sampling technique is being used in the research participants because this technique allows the selection of the most suitable sample population for collecting data for this research (Nyimbili and Nyimbili, 2024; Campbell *et al.,* 2020). For conducting qualitative interviews, the two cancer specialists have been identified on LinkedIn based on their years of experience, and they have been approached using their LinkedIn profiles.

3.3 Data collection and analysis

The data will be collected using an open-ended questionnaire consisting of three questions directly relevant to the research context. The data will be collected through an online interview, and the transcripts have been generated for further data analysis. The data analysis will be done using a thematic analysis framework of Braun and Clarke. The thematic analysis framework helps in identifying recurring patterns in data to generate codes and combining them to form meaningful patterns relevant to research objectives (Terry and Hayfield, 2021; Jowsey *et al,* 2021). Furthermore, the primary data is supported by secondary data such as journal articles, web sources, and other sources of information to validate the research findings.

3.5 Ethical considerations

This study will take informed consent from all research participants to ensure voluntary participation in the research (Klykken, 2022). The right to withdraw will also be informed to the participants (Florea, 2023). No personal information from the participants has been collected to express their years of experience in the field of cancer, and only answers to the interview questionnaire have been obtained.

3.6 Validity and reliability

The validity of the research will be ensured through the triangulation of interview findings with the literature review and secondary data. In order to ensure reliability, direct quotes from the interview transcripts will be included, and data will not be manipulated in any manner.

4. Results and Discussion

The key themes which have emerged from the interview findings are that nanotechnology helps in early and accurate diagnosis, improves patient outcomes and prognoses and the barriers to its implementation involve high costs, low accessibility and integration within conventional systems.

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4.1 Early Diagnosis Accuracy

One of the key findings from the interview has been that nanotechnology is significantly improving the accuracy in diagnosing cancers, along with facilitating early diagnosis. Oncologist A said that *"Tools like nano-biosensors and quantum dots detect cancer biomarkers at very low concentrations at the molecular level…… This level of sensitivity has made early detection much more reliable, especially in cancers that are hard to detect and quite progressive".* At the same time, Oncologist B stated that *"Devices like nanoparticle contrast agents and biosensors have increased sensitivity and specificity, improving detection accuracy in high-risk patients. This precision helps us begin treatment plans earlier and avoid unnecessary delays in treatment."* This has further been supported by Sun *et al.* (2023) and Sargazi *et al.* (2022), who suggest that upon injection, gold nanoparticles bind specifically to cancer cells and scatter light, thus causing doctors to easily identify tumours and distinguish them from healthy cells.

4.2 Patient Outcomes and Prognosis

The interview responses also showed that early detection through nanotechnology improves survival rates. As per Oncologist A, "*Patients diagnosed at stage I or II typically require less aggressive treatment and show higher recovery rates. It also allows for tailored and precise therapies, reducing complications and enhancing quality of life".* And this has also been addressed by Oncologists B, who mentioned that early detection of cancer using nanotechnology limits side effects of treatments, leading to better recovery and lower healthcare costs. Early detection leads to early intervention and leads to positive treatment outcomes and offers time to clinicians for optimising treatment procedures (Goldstar Rehabilitation, 2025).

4.3 Cost, Accessibility, and Implementation Challenges

However, its use of technology for the detection of cancer has faced significant challenges such as high costs, a lack of trained personnel and inadequate infrastructure (Chinthala, 2023). In addition, oncologist B also mentioned that *"Nanotechnology's potential is immense, but its accessibility is limited by financial constraints, lack of awareness, and regulatory hurdles."* It has also been identified that in low settings, the availability of basic diagnostic tools is listed as introducing nanotechnology on topics that require significantly high levels of investments.

4.4 Discussion

The findings have demonstrated that nanotechnology significantly enhances the early and accurate diagnosis of cancer through the use of tools like nano-biosensors and quantum dots, which detect cancer biomarkers at ultra-low concentration (Salaudeen and Akinniranye, 2024;

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Nasir *et al.,* 2021). The research participants have also confirmed that this precision ability of nanotechnology helps in precisely locating cancer cells and improving the outcomes of patient prognosis (Goldstar Rehabilitation, 2025). In addition, it has also been noted that the use of Quantum dots enables superior imaging due to their high photostability and fluorescence (Devi *et al.,* 2022; Naik et al., 2022). This supports the use of quantum dots in detecting hard-to-identify cancers. However, the barriers which have been identified to the implementation of nanotechnology are high implementation costs and a lack of accessibility.

5. Conclusion

5.1 Key findings

The key findings which have been found from this study are that nanotechnology enables early and accurate detection of cancer through the use of advanced tools like quantum dots and nano-biosensors. The interview with the oncologist confirmed that nanotechnology has the ability to identify cancer biomarkers at ultra-low concentrations, thus improving diagnostic precision and clinical outcomes.

5.2 Benefits of using nanotechnology

The key benefit of using nanotechnology has been identified as being that it is noninvasive, highly sensitive and offers targeted diagnostic solutions. It enhances imaging, enabling early intervention, reduces systemic toxicity and improves patient prognosis.

5.3 Call for further research or application in real-world diagnostics

Based on the findings, it can be said that future research is essential for addressing issues with cits, accessibility and implementation barriers and identifying the ways through which the integration of nanotechnology into real-world systems could be facilitated to revolutionise cancer diagnostics.

6. Recommendations for Future Research

It can be recommended that future research could be conducted with a focus on exploring the long-term effects of nanoparticles on human health and the environment to ensure that they are completely safe to be used in diagnosis on a larger scale. The focus on studies assessing the integration of AI within Nano diagnostics can enhance precision, real-time analysis of data and understanding of predictive accuracy of nanoparticles in cancer detection. In addition, in future, more clinical trials need to be conducted for developing a better understanding regarding the real-world application of nanotechnologies.

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7. Conflict of Interest

The author declares no conflict of interest."

8. Funding

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