

HEALTH, ENVIRONMENT, DEVELOPMENT**BIOREALIZATION ENGINEERING TECHNOLOGIES FOR CANCER
DIAGNOSIS: IMPACT ON THE HEALTH SYSTEM****Valeriia Kushnyr**

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Summary

This article delves into the analysis of the impact of bio-realization engineering technologies on cancer diagnostic processes within the contemporary healthcare system. The objective of the article is to identify the potential of molecular-genetic testing and other bio-realization methods in enhancing diagnostic capabilities and therapeutic approaches for oncological diseases. To achieve this goal, general scientific methods of analysis and synthesis of existing research in this field are utilized, including a review of scientific literature and a critical analysis of the results of experimental studies. The findings confirm the significant impact of bio-realization engineering technologies on the advancement of cancer diagnostics. Specifically, molecular-genetic testing opens new avenues for early detection and personalized treatment approaches for cancer, based on the genetic characteristics of tumors. These technologies are particularly valuable for countries with limited medical resources, as they offer cost-effective and efficient solutions that provide broader access to quality diagnostic services. They also contribute to improving the overall efficacy of treatment strategies and optimizing medical research, reducing the burden on medical staff. The practical significance of the obtained results lies in the possibility of their application in the development of new diagnostic tools and techniques aimed at enhancing the accuracy, accessibility, and efficiency of cancer treatment. This, in turn, may contribute to reducing mortality from oncological diseases and improving patients' quality of life. Bio-realization engineering technologies, particularly molecular-genetic testing, play a pivotal role in modern oncological diagnostics, offering promising opportunities for the improvement of diagnostic and therapeutic procedures for cancer. Their integration into the healthcare system enhances diagnostic accuracy, treatment accessibility, and the overall level of medical services, opening new horizons in the fight against oncological diseases.

Key words: molecular-genetic testing, bio-realization engineering technologies, cancer diagnostics, healthcare system, personalized treatment.

DOI <https://doi.org/10.23856/6329>

1. Introduction

In recent decades, engineering technologies have advanced rapidly, introducing innovative approaches across numerous fields, including healthcare. Among these innovations, bio-realization technologies hold a special place, promising to revolutionize cancer diagnostics. This topic is particularly relevant given the high incidence of cancer worldwide and the critical need to improve access to quality diagnostic services.

The issue of access to precise and effective diagnostic tools is especially pressing in developing countries, where approximately 70% of cancer cases are diagnosed at advanced stages of the disease (*Mayoral-Peña et al., 2022*). In developed countries, the situation is somewhat better, yet still problematic. For instance, in 2019, the United States diagnosed 1,806,590 new cases of cancer, with 606,520 fatalities. The most common types of cancer include breast cancer, lung and bronchial cancer, prostate cancer, colorectal cancer, among others. It is also noted that approximately 39.5% of men and women will be diagnosed with cancer at some point during their lifetimes (*Cancer Statistics, 2023*). The overall cancer mortality rate has been declining since the early 1990s, indicating progress in combating the disease. However, challenges remain, particularly in light of the rise of other risk factors, such as obesity in the United States (*Lorenzoni, 2019*).

Over the past two decades, there has been a rapid increase in the availability and use of diagnostic imaging technologies, such as CT, MRI, and PET scanners, in most OECD countries. Japan, Australia, the United States, and Denmark are among the countries with the highest number of these diagnostic technologies per capita. A high level of utilization of these diagnostic scanners was noted in the United States, Austria, and Iceland, where more than 340 examinations per 1,000 population were conducted in 2019. Such high usage underscores the critically important role of these technologies in the diagnosis and treatment of cancer (*OECD, 2021*).

Furthermore, the cancer diagnostics market is expected to grow significantly, especially in North America, driven by an increasing burden of oncological diseases and a focus on the development of new diagnostic devices. Statistics from the American Cancer Society indicate an increase in the number of new cancer cases in the US from 1,918,030 in 2022 to 1,958,310 in 2023. Government initiatives, such as President Biden's "Cancer Moonshot," aim to halve the cancer mortality rate over 25 years, which will contribute to further growth in the cancer diagnostics market (*Cancer Statistics, 2023*).

The objective of the article is to identify the potential of molecular-genetic testing and other bio-realization methods in enhancing diagnostic capabilities and therapeutic approaches for oncological diseases.

2. The Significance of Bio-Realization Engineering Technologies for Cancer Diagnostics

Accurate diagnosis is the first and a crucial step in treating any disease. This is particularly true for malignant pathologies, where a well-chosen examination can literally be life-saving. Modern diagnostics of oncological diseases encompass a range of cutting-edge medical technologies and methods, enabling the acquisition of more comprehensive information about the development of malignant tumors and conducting their treatment with higher effectiveness. Currently, there are diagnostic techniques that allow for precise determination of the cancer type, its stage, size, characteristic gene mutations, and many other features. This empowers physicians to employ a personalized approach to treatment, select the most effective strategy, monitor therapy effectiveness, and promptly detect recurrences.

During oncological diagnostics, various groups of complementary studies are utilized. Innovative cancer diagnostic methods hold particular significance for making accurate diagnoses, providing physicians with the most crucial and precise information, revealing unique data about the tumor, and offering a complete picture of the disease. This, in turn, allows for the application of an individualized treatment approach for each patient and significantly improves therapeutic outcomes (*Gu et al., 2009*).

Among the most sought-after and accurate cancer diagnostic methods are:

– Magnetic Resonance Imaging (MRI): This method uses magnetic fields and radio waves to create detailed images of organs and tissues within the body. MRI is particularly useful for visualizing soft tissues such as the brain, spinal cord, and internal organs.

– Positron Emission Tomography with Computed Tomography (PET-CT): This method combines PET and CT technologies, allowing for the simultaneous acquisition of high-resolution images and information about the metabolic activity of tissues. PET-CT is especially effective for detecting cancer and metastases.

– Stereotactic Biopsy: This high-precision biopsy method uses computer guidance to accurately determine the tumor's location in three dimensions, enabling precise tissue sampling for histological examination, even from hard-to-reach areas.

– Endoscopic Diagnostics: Using a thin, flexible tube with a camera at the end (endoscope), this method allows doctors to directly examine internal organs and channels, such as the gastrointestinal tract, respiratory pathways, and even some blood vessels.

– Molecular-Genetic Testing: This method analyzes genes, chromosomes, and proteins in cancer cells, allowing for the identification of specific mutations and markers. Molecular-genetic testing can indicate the most effective treatment methods for certain types of cancer and the risk of disease development in relatives (*Pantel et al., 2024*).

3. Bio-Realization Engineering Technologies for Cancer Diagnostics: Practical Applications

Molecular-genetic testing represents a category of bio-realization engineering technologies employed in cancer diagnostics. This technology involves the development and use of biomarkers that are specific to certain types of cancer cells or DNA mutations associated with oncological diseases. It enables the identification of genetic anomalies at the molecular level, providing valuable information for early diagnosis and determining the optimal treatment.

Molecular-genetic testing is an innovative direction in the diagnosis and treatment of oncological diseases, based on the analysis of genetic markers and DNA mutations associated with cancer development. This method allows for the identification of unique genetic characteristics of a specific tumor, facilitating the selection of personalized treatment with higher chances of success (*Wilchek, Bayer, & Livnah, 2006*).

The evolution of bio-recognition systems, such as antibodies that play a key role in recognizing and binding with specific target molecules, is fundamental to the development of molecular-genetic diagnostic tests (*Williams, Stephens, O'Brien, & Zhou, 2004*). These tests are used to determine the presence or absence of specific mutations or gene expressions that may indicate a predisposition to certain types of cancer or a response to specific treatment methods.

Significant progress in understanding the molecular mechanisms of cancer diseases and the development of bio-recognition technologies, particularly molecularly imprinted polymers (MIPs) and recombinant antibodies, greatly expands the possibilities for early diagnosis and effective cancer treatment (*Landry, Ke, Yu, & Zhu, 2015*).

These achievements not only contribute to increasing the accuracy and sensitivity of diagnostics but also open new perspectives for developing personalized therapeutic strategies targeting specific genetic markers in tumor cells, ensuring greater treatment efficacy and fewer side effects (*Haßel & Mayer, 2019*).

Molecularly Imprinted Polymer (MIP) technology represents an innovative approach in medical science, especially in the field of oncology. It involves creating synthetic polymers with embedded molecular "imprints" that have selective affinity for specific biomolecules, particularly those associated with cancer diseases.

Let's explore the main functions and applications of MIPs in oncology:

- Fluorescent Biovisualization: MIPs are used for visualizing hyaluronic acid, a key component of the tumor matrix (*Alexander et al., 2006*). This allows for precise determination of the localization and size of tumor formations.

- Targeted Drug Delivery: Applying MIPs in the form of nanocarriers with quantum dots to transport anti-tumor drugs directly to cancer cells, thereby reducing the impact on healthy tissues (*Cieplak & Kutner, 2016*).

- Enhancement of Radiotherapy: Using MIPs incorporated with gold nanoparticles in microgels to increase the effectiveness of radiotherapy while minimizing damage to healthy tissues (*Kissinger, 2005*).

- Electroanalytical Detection of Medications: MIPs are used to simplify the process of detecting medications, such as 6-mercaptopurine used in leukemia treatment, in biological samples (*Bazin et al., 2017*).

- These applications of MIPs in oncology demonstrate their significant potential both in diagnostics and treatment of cancer, enabling more personalized and effective approaches.

4. Advantages and Disadvantages of Bio-Realization Engineering Technologies

Bio-realization engineering technologies, such as Molecularly Imprinted Polymer (MIP) technology, play a significant role in advancing medicine by offering innovative approaches to diagnostics, treatment, and disease monitoring. MIP involves creating selective ligand recognition sites in synthetic polymers that can interact with specific molecules like proteins, peptides, or nucleotides with high specificity and sensitivity. This allows for the use of MIPs in a wide range of applications, from developing new diagnostic biosensors to creating targeted drug delivery systems.

Let's consider the advantages of this technology:

- Cost-effectiveness: MIPs are relatively inexpensive to produce compared to natural bioreceptors like antibodies.

- Stability: Molecularly imprinted polymers are highly stable under various conditions, including a wide range of pH levels and temperatures, making them ideal for diverse applications.

- Durability: MIPs can retain their functionality over a long period, ensuring a long lifespan for diagnostic and therapeutic systems.

- Scalability: The technology allows for mass production of polymers, critical for commercialization.

Now, let's look at the disadvantages:

- Binding Capacity: A limited number of binding sites may reduce the efficiency of interaction between the polymer and the target molecule.

- Non-specific Binding: There is a potential for non-specific binding due to physical interactions between the polymer and other molecules, which can affect accuracy and specificity.
- Accessibility of Binding Sites: In some cases, the binding sites may be physically inaccessible to target molecules due to the structural features of the polymer.
- Polymer Rearrangement: Long-term use or extreme conditions can lead to rearrangement or degradation of the polymer structure, affecting its functionality.

Overall, the positive aspects of MIPs, such as high specificity, stability, and cost-effectiveness, make them a promising technology for various medical applications. However, to fully realize their potential, it's important to consider and minimize possible downsides, including limitations in binding capacity and risks of non-specific binding.

5. The Impact of Bio-Realization Engineering Technologies on Cancer Diagnostics in the Healthcare System

The impact of bio-realization engineering technologies, particularly Molecularly Imprinted Polymers (MIPs), on cancer diagnostics within the healthcare system is significant and multifaceted. These technologies pave new paths for early detection and precise diagnosis of cancerous conditions, which is critically important for enhancing treatment effectiveness and increasing patients' chances of successful recovery.

Prospects and impact on cancer diagnostics:

- Early Detection: MIPs provide highly specific recognition of cancer biomarkers, which can facilitate the early detection of subtle tumor formations. This, in turn, increases the chances of successful treatment and reduces the risk of complications.
- Personalized Diagnostics: The use of MIPs allows for the customization of diagnostic approaches to individual genetic features of patients, ensuring more accurate determination of cancer type and stage.
- Efficiency and Cost Reduction: MIPs have the potential to lower the cost of diagnostic tests due to their high stability, long shelf life, and ease of production scaling. This can lead to broader access to quality diagnostic services.
- Diagnostic Innovation: The introduction of MIPs into medical practice stimulates the development of innovative diagnostic methods that include nanotechnology, electrochemical detection, and fluorescent visualization.

Bio-realization engineering technologies, specifically Molecularly Imprinted Polymers (MIPs), are revolutionizing approaches to cancer diagnostics in the healthcare system, especially in countries with limited resources. These technologies offer an economical and efficient solution for early detection and accurate diagnosis of cancer, providing access to quality medical services to a wider population. The significance of MIPs lies not only in their ability to precisely identify cancer biomarkers but also in the scalability and stability of these polymers, making them ideal for use under various medical conditions.

Since MIPs can be produced at a lower cost compared to traditional bioreceptors, they have the potential to reduce the cost of diagnostic tests, making them more accessible to medical facilities in countries with limited budgets. This could lead to a wider implementation of early screening and cancer diagnostics, increasing the chances of successful treatment.

In developed countries, the use of MIPs is also significant due to their potential to enhance the accuracy of diagnostic methods and treatment effectiveness. The introduction of these technologies can contribute to further automation and optimization of medical research, reducing the burden on medical staff and improving the overall quality of healthcare services.

6. Conclusions

The application of bio-realization engineering technologies, particularly molecular-genetic testing, is significantly transforming approaches to cancer diagnostics within the global healthcare system. These technologies, grounded in the analysis of genetic markers and mutations, are unveiling new possibilities for early detection of oncological diseases and the development of personalized treatment strategies. Their capacity to identify unique genetic characteristics of tumors at the molecular level facilitates the selection of targeted treatments, enhancing patients' chances of successful recovery.

Bio-realization engineering technologies prove especially valuable for countries with limited resources, where access to quality medical care is often constrained. The cost-effectiveness, stability, and scalability of molecular-genetic testing can provide broader access to advanced diagnostic services, improving early detection and treatment of cancer in these regions. Thus, bio-realization engineering technologies have the potential to uniformly elevate the quality of medical care on a global level, making cutting-edge diagnostic solutions accessible to a wider patient demographic.

However, it's also essential to consider potential limitations and challenges associated with the implementation of these technologies, such as the risk of non-specific binding and limited binding capacity. Active research and further optimization of bio-realization engineering technologies can help overcome these hurdles, ensuring their more effective application in clinical practice.

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