



Innovative methods of early cancer diagnosis: from genetic screening to liquid biopsy

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Summary

Objective: This study aims to explore the advantages and disadvantages of both traditional and innovative methods of cancer diagnosis. The study includes an overview of the concept of cancer, its types, and its root causes.

Methods: Classical methods of cancer diagnosis like radiography, puncture biopsy, computed tomography, magnetic resonance imaging, ultrasound, positron emission tomography, mammography, blood tests for cancer markers, endoscopy, and fibrobronchoscopy are examined for their pros and cons. The paper also examines innovative methods for diagnosing cancer pathology, like liquid biopsy, next-generation sequencing, microRNA analysis, exosome analysis, genetic screening based on electrochemical detection of circulating tumor cells, and genetic screening using circulating free DNA.

Results: The study reveals that conventional methods are invasive and risky, while modern technologies detect molecular markers safely to detect cancer early. Liquid biopsy is helpful at monitoring tumor disease progression without surgery. Next-generation sequencing can find rare genetic mutations, which aids tailored treatment. MicroRNA and exosome analysis provides molecular markers of tumor aggressiveness and responsiveness to treatment.

Conclusion: The main limitation of the latest methods is their high costs and the need for specialized equipment and trained specialists, which reduces the availability of such technologies.

KEYWORDS: *oncology; disease detection; latest technologies; disease prediction; cancer markers*

INTRODUCTION

Cancer is one of the leading causes of death in the world, and early diagnosis is key for successful treatment. Innovative methods such as genetic screening and liquid biopsy provide new opportunities for noninvasive detection of cancer cells at an early stage, which can substantially improve treatment prognosis. Despite the prospects for implementing these methods, medicine faces technical and economic challenges, in particular, regarding the accuracy of tests and the availability

of technologies. In addition, genetic screening can detect mutations that do not always lead to cancer, increasing the risk of overdiagnosis.

Some studies focus on the latest therapeutic approaches to the treatment of cancers such as breast, lung, and multiple myeloma. Liu et al.(1), assessed the effectiveness of small molecules, antibodies, antibody-drug conjugates, and new technologies such as cell and gene therapy. The prob-

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lem was that, despite significant advances in cancer therapy and the approval of more than 77 new cancer drugs, most forms of cancer remained incurable. The researchers' findings showed that new technologies have substantially expanded therapeutic opportunities, opening up new perspectives for patients. Another paper examined the integration of interventional oncology and immunotherapy as a way to improve the treatment of cancer patients. Thus, Erinjeri et al.(2), focused on traditional approaches to cancer treatment, which often did not produce the necessary results, so it became necessary to integrate minimally invasive methods, such as interventional oncology with immunotherapy, to improve patient survival. The authors determined that the combination of these approaches, in particular, the use of immunotherapy to activate the patient's immune system, improved treatment outcomes and may play an important role in future cancer treatment plans.

Precision oncology based on nuclear magnetic resonance (NMR) for the stratification of breast cancer patients was also considered. The problem described by Vignoli et al.(3), was the heterogeneity of breast cancer, which made it difficult to determine optimal treatment strategies. The authors investigated metabolic approaches to better understand the biochemical characteristics of tumors and stratify patients to assign them individual treatment plans. The results of the study showed that NMR metabolomics can be promising for personalized treatment of breast cancer patients, in particular, for predicting the risk of relapse and avoiding unnecessary chemotherapy.

The studies by Ettinger et al.(4), and Smith and Prasad(5) presented clinical guidelines for the treatment of patients with non-small cell lung cancer (NSCLC) and the use of monoclonal antibodies and low-molecular-weight inhibitors. The problem was the need to create updated guidelines for the diagnosis and treatment of NSCLC, including the use of immunotherapy and targeted methods. The authors emphasized that patients with metastatic lung cancer who were suitable for targeted therapy had a substantially better chance of survival. The findings highlighted the importance of targeted therapies, and although targeted therapies improved survival for some patients, such drugs had substantial side effects and high costs, which limited their use, but they could still be effective in treating patients with mutations with current methods.

The use of oncolytic viruses for cancer treatment was also examined. Cao et al.(6), focused on the problem that traditional treatments such as chemotherapy and radiotherapy often do not provide long-term remission in patients with advanced cancer. The authors investigated several types of viruses, such as herpes virus and adenovirus, that can be genetically modified to kill cancer cells without damaging healthy tissues. The results showed that oncolytic viral therapy has substantial potential for treating severe forms of cancer, but further clinical trials are needed to optimize efficacy.

Abdelrahim et al.(7) considered a new direction in oncology-transplant oncology. The authors investigated the use of organ transplantation in patients with liver cancer and liver metastases. The problem was the need to expand liver transplant indications for cancer patients. The results showed that transplant oncology, especially when combined with immunotherapy, substantially improved the survival rate of patients with limited systemic therapy options. Other studies have explored the prospects of immunotherapy based on natural killer cells (NK cells) in the fight against cancer. The dilemma highlighted by Demaria et al.(8), was that many patients did not benefit from existing immunotherapy methods, so the authors proposed new strategies for activating innate immunity to fight tumors. The results showed that new antibodies targeting NK cells can improve the effectiveness of immunotherapy and provide long-term tumor control.

Therefore, although many studies have been devoted to the treatment and diagnosis of cancer, there are not enough papers that specifically focus on the latest diagnostic methods, such as genetic screening, liquid biopsy, etc., and this was the basis for the current study. The purpose of the study is to identify the possibilities of using innovative methods of early cancer diagnosis, from genetic screening to liquid biopsy, to improve the effectiveness of detecting diseases at an early stage. The following research objectives were set to achieve the goal: the concept of cancer, its types, and root causes were analyzed; classical and innovative methods of cancer diagnosis, including genetic screening and liquid biopsy, were studied; and the advantages and disadvantages of both classical and new methods of cancer diagnostics were considered.

THEORETICAL REVIEW

Cancer involves the uncontrolled growth of abnormal cells that can invade surrounding tissues and metastasize to other parts of the body. This abnormal proliferation usually occurs due to genetic mutations that disrupt normal cell functions such as division, differentiation, and apoptosis. Cancer cells avoid mechanisms that regulate growth and death, which allows them to continuously divide and form tumors. Over time, they evolve, acquiring mechanisms to avoid the immune system and maintain continuous growth(9, 10).

Cancer can be benign or malignant, and the latter is capable of aggressive spread through metastases. Cancer development is often triggered by genetic mutations that can be inherited or caused by external factors, such as carcinogens (tobacco smoke, radiation), unhealthy lifestyles, and viral infections (human papillomavirus, hepatitis)(11, 12). These mutations disrupt the mechanisms of the cell cycle, leading to constant cell division and the accumulation of genetic errors. Cancer cells accumulate additional mutations that allow them to avoid immune surveillance and stimulate angiogenesis, making them resistant to standard treatments(13, 14).

Impaired cell cycle control allows cancer cells to divide despite DNA damage, which contributes to their aggressive behavior(13). They not only disrupt the normal functions of the tissues in which they occur but also actively interact with the microenvironment, which includes other cells, blood vessels, and components of the immune system. This environment is critical for the survival and progression of tumors. The interaction between tumor cells and their microenvironment allows cancer to adapt to different conditions and provides resistance to various forms of therapy(15).

Timely detection of cancer still presents a challenge. In the early stages, cancer is often successfully treated, but when it spreads to other organs, treatment becomes more complex and requires combined approaches such as chemotherapy, radiotherapy, and targeted therapy. The complexity of cancer and its ability to adapt make it necessary to take an individualized approach to treatment based on the characteristics of each tumor(16).

Cancer is a significant global health issue, with breast, lung, colon, prostate, and skin cancers being among the most common types. Lung can-

cer, for instance, requires careful assessment of tumor spread to determine effective treatment strategies, particularly in the context of personalized medicine(17). Breast cancer is the most prevalent cancer among women, with invasive ductal carcinoma being the most common form. This type of cancer exhibits considerable heterogeneity, influencing its clinical progression and treatment response(18). Skin cancer, the most widespread cancer globally, includes melanoma as its most aggressive subtype. Early detection of melanoma is crucial for successful treatment, and advancements in machine learning are enhancing the potential for early diagnosis(19).

The main causes of cancer are gene mutations, both inherited and acquired. Damage to oncogenes and tumor suppressor genes is the central mechanism of occurrence of most cancers, which leads to uncontrolled cell growth(20). Infections such as human papillomaviruses, hepatitis B and C viruses, and the bacterium *Helicobacter pylori* are major risk factors for developing certain types of cancer, especially in low- and middle-income countries. For example, hepatitis virus infections can cause liver cancer, and human papillomavirus is the main cause of cervical cancer(21, 22).

Oxidative stress plays a key role in DNA damage and the initiation of cancer development. Excessive production of reactive oxygen species can lead to mutations and disrupt the mechanisms of DNA repair(23). Metabolic disorders are also an important factor in the development of cancer. Dysfunction of glucose and fatty acid metabolism becomes not only a characteristic of cancer but also a mechanism of its development. Most oncogenes or tumor suppressor genes support these metabolic changes, promoting tumor progression. The immune system plays a crucial role in the fight against cancer since, with a weakened immune response, tumor cells can escape control and multiply(24, 25). About 30-50% of cancers can be prevented by changing the lifestyle and eliminating bad habits. Quitting smoking, limiting alcohol consumption, improving nutrition, and increasing physical activity can substantially reduce the risk of many cancers(26). Thus, cancer is the result of a complex interaction of genetic mutations, metabolic disorders, infections, and external factors, making it one of the biggest challenges for modern medicine.

MATERIALS AND METHODS

In the first stage, the concept of cancer, its types, and root causes are analyzed. Various types of cancer are examined, including breast, lung, stomach, and other cancers. In addition, the factors that can lead to the development of cancer pathologies, in particular, genetic mutations and exposure to carcinogens and infectious agents, were considered.

The search and selection of the literature for the study were conducted in stages. Initially, keywords and phrases were used to generate search queries in the PubMed, Scopus, and Web of Science databases. The keywords included *innovative methods for early cancer diagnosis, genetic screening, liquid biopsy, circulating tumor DNA, microRNA, next-generation sequencing, cancer markers, non-invasive cancer diagnosis*, and other terms related to modern approaches to cancer detection. Special attention was paid to papers that were published in the last five years to ensure that the data was relevant and up-to-date. The search covered publications in leading peer-reviewed journals on oncology, molecular biology, and medical diagnostics. After conducting an initial keyword search, 120 publications were identified (Figure 1).

Further, the received papers were analyzed for compliance with the inclusion and exclusion criteria. The main criteria for inclusion were publication in a reputable peer-reviewed scientific journal; the study should focus on early cancer diagnosis using modern methods such as liquid biopsy, ctDNA, microRNA, and other more classical methods chosen for analysis for cancer diagnosis; it should contain the results of clinical trials or experimental data confirming the effectiveness of the method; and the literature should be published mainly in the last five years to ensure the novelty of the results obtained. The exclusion criteria included publications that did not address early diagnosis methods but focused on therapeutic approaches or other aspects; did not have sufficient data for statistical analysis or were published more than five years ago, in addition to fundamental works on this subject; did not have a review; or did not meet the criteria of scientific quality.

After careful analysis and evaluation of the selected sources, the total number of papers was reduced to 53. The selected sources covered the latest technologies in cancer diagnosis, including

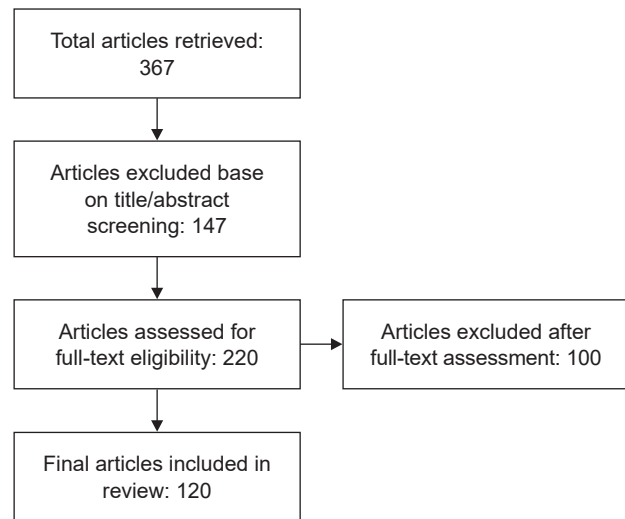


Figure 1. The process of identifying, evaluating, excluding, and including studies

their advantages, limitations, and prospects for use in clinical practice. This approach to selection allowed ensuring the scientific quality and relevance of the study.

In the future, when considering classical diagnostic methods, such as radiography, puncture biopsy, computed tomography, magnetic resonance imaging, ultrasound, positron emission tomography, mammography, blood tests for cancer markers, endoscopy and fibrobronchoscopy, a detailed analysis of each of these methods was conducted. In addition to considering their use in clinical practice, their capabilities and limitations are analyzed in the context of the effectiveness of detecting various types of cancer pathologies. The next phase of the study focused on the analysis of innovative diagnostic methods such as liquid biopsy, next-generation sequencing, microRNA analysis, exosome analysis, genetic screening based on the analysis of circulating tumor cells, electrochemical detection, and genetic screening using circulating free DNA. During this stage, it was analyzed how these methods are used to detect cancer cells at an early stage and what limitations may arise when using them.

In the course of the study, the methods of content analysis and comparative analysis were used. Content analysis has helped structure information about various innovative diagnostic methods, such as liquid biopsy, next-generation se-

quencing, and exosome analysis. The comparative analysis compared these methods with classical approaches, highlighting the advantages and disadvantages of each approach, which is critical for choosing the appropriate method of early diagnosis. In addition, clinical studies were reviewed that provide data on the practical application of innovative methods in various cancer clinics.

The results obtained were interpreted using an analytical approach, which allowed identifying the most effective methods of early diagnosis. Evaluation was based on patient sensitivity, specificity, and safety criteria.

RESULTS AND DISCUSSION

Classical methods of cancer diagnosis play a critical role in medical practice, laying the foundation for the development of modern oncology. Their introduction was a revolutionary step in the detection and treatment of malignancies, as they allowed doctors to see cancerous formations, understand their characteristics, and develop appropriate treatment strategies. Due to these methods, the patient survival rate has substantially increased, and opportunities for more detailed examination of tumors have expanded. Despite the emergence of the latest technologies, classical

methods are still important and widely used because of their reliability and proven effectiveness.

Table 1 presents a generalized list of the most well-known classical methods for diagnosing cancer pathologies with their characteristics.

RADIOGRAPHY

Radiography is one of the earliest methods used in cancer diagnostics, based on the visualization of internal structures through X-ray imaging. It is particularly effective in identifying skeletal abnormalities and thoracic pathologies, including lung malignancies. As for the advantages of such diagnostic methods, radiography is a fast and accessible method that allows rapid detection of abnormal formations and pathological changes in various organs and tissues. It is particularly effective for diagnosing cancerous lesions of the bones and lungs, providing high-quality images in a short time. Due to its availability, radiography is widely used in initial examinations, which contributes to rapid diagnosis and further treatment planning. Radiography lacks sensitivity for soft tissue contrast and may fail to detect small or early-stage tumors. It also presents cumulative radiation risks when used frequently and lacks three-dimensional imaging capacity.

Table 1.

Classic methods of cancer diagnosis

Diagnostic method	Characteristics
Radiography	A classic diagnostic method involving the use of X-rays to visualise internal organs to identify possible tumours
Puncture biopsy	Method for obtaining a tissue or fluid sample using a needle to test for cancer cells
Computed tomography (CT)	A method of X-ray diagnostics that allows getting detailed layer-by-layer images of organs and detecting tumours
Magnetic resonance imaging (MRI)	An imaging technique that uses a magnetic field to create detailed images of organs and tissues
Ultrasound examination	A non-invasive imaging technique that uses sound waves to create images of internal organs that help detect tumours
Positron emission tomography (PET)	A method of nuclear medicine that allows visualising the functional activity of tissues to detect malignancies
Mammography	X-ray method of breast examination used for early detection of breast tumours
Blood test for cancer markers	Critical review of various types of cancer markers used to detect cancer in the blood, including CEA, PSA, and alpha-fetoprotein
Endoscopy	A method that allows examining internal organs and cavities using a special flexible tube with a camera for detecting tumours
Fibrobronchoscopy	Endoscopic method of bronchial examination for the diagnosis of lung cancer

Source: compiled by the authors based on Silvestri et al.(27), Wen et al.(28), Wang(29).

PUNCTURE BIOPSY

A puncture (needle) biopsy, in turn, is a very accurate and important method for confirming a cancer diagnosis, as it allows obtaining a tissue sample for microscopic analysis, enabling doctors to make an accurate diagnosis and understand the type and stage of the tumor. A puncture biopsy is minimally invasive and can be performed under the control of ultrasound or CT, which ensures high accuracy of the procedure. It enables the rapid acquisition of the necessary information to determine the most effective treatment. The technique may not capture the heterogeneity of the tumor, and inadequate sampling can compromise diagnostic accuracy. Risks include bleeding, infection, and inconclusive results due to insufficient cellular material.

COMPUTED TOMOGRAPHY (CT)

CT imaging combines multiple X-ray measurements to produce detailed cross-sectional images of internal structures, which are essential in cancer staging. It offers precise anatomical localization, enabling detection of small tumors and assessment of metastatic spread. CT is indispensable for surgical planning and treatment monitoring. The method involves significant radiation exposure, which is concerning with repeated use. Contrast agents used to enhance images may cause adverse reactions or renal complications.

MAGNETIC RESONANCE IMAGING (MRI)

Magnetic resonance imaging provides high-precision images of soft tissues, making it ideal for diagnosing tumors of the brain, spinal cord, pelvic organs, and other structures. MRI does not use ionizing radiation, which makes it safe for repeated use. Due to its accuracy, MRI can detect even the slightest changes in tissues, which allows doctors to make informed decisions about treatment in the early stages of the disease. MRI is time-consuming, expensive, and contraindicated in patients with metal implants. Accessibility may be limited in low-resource settings.

ULTRASOUND EXAMINATION

Ultrasound is a non-invasive and safe method that allows quickly obtaining an image of internal organs using sound waves. Ultrasound is widely used to diagnose soft tissue tumors such as those in the liver, kidneys, mammary glands, and thyroid. In addition, ultrasound helps to perform puncture biopsies with maximum accuracy. This method can also be used repeatedly, which allows doctors to monitor the treatment process and the patient's condition without the risk of radiation exposure. It has limited penetration depth, which hampers evaluation of deep or bony structures. Diagnostic accuracy depends on the operator and patient-specific factors, such as obesity.

POSITRON EMISSION TOMOGRAPHY

Positron emission tomography (PET) can assess the metabolic activity of cells and is a very sensitive method for detecting cancer cells. PET enables detection of tumors and metastases even at an early stage, when they are not yet visualized by other methods. PET is often used in combination with CT scans to produce the most accurate images possible, allowing doctors to assess both the structural and functional features of the tumor. This makes PET an important tool for assessing the spread of cancer and monitoring the effectiveness of treatment. But, PET is expensive and requires complex logistics involving radioactive tracers. It lacks detailed anatomical visualization unless paired with CT or MRI.

MAMMOGRAPHY

Mammography is the “gold standard” for early detection of breast cancer. It uses X-rays to create detailed images of breast tissue and can detect even small neoplasms or calcifications that may indicate the presence of a tumor at an early stage. Mammography is an essential tool for screening middle-aged and older women, as it allows detecting cancer even before the appearance of physical symptoms, which substantially increases the chances of successful treatment. Regular mammograms help reduce breast cancer mortality through early detection and treatment. Its sensitivity declines in women with dense breast tissue. Radiation exposure,

although low, remains a concern with regular screenings, and false positives may cause unnecessary anxiety and interventions.

BLOOD TESTS FOR CANCER MARKERS

A blood test for cancer markers is a main diagnostic tool that can detect specific substances produced by cancer cells or the body in response to tumor development. This allows not only the suspicion of the presence of cancer at an early stage but also the control of the course of the disease during treatment. Analysis for cancer markers can be used to monitor the effectiveness of therapy, detect relapses, or assess the progress of the disease. This method is simple and affordable and can be combined with other diagnostic methods to get a more complete picture of the patient's condition. Marker specificity and sensitivity are limited; many benign conditions can elevate marker levels, and such tests do not localize tumors.

ENDOSCOPY

Endoscopy is a high-precision imaging technique that allows doctors to examine internal organs using a special instrument with a camera (endoscope) that is inserted through natural openings of the body or through small incisions. Endoscopy is particularly useful for detecting tumors in the gastrointestinal tract, esophagus, stomach, colon, and bronchi. In addition to imaging, this method helps take tissue samples for a biopsy or even perform small surgical procedures. Due to its accuracy, endoscopy detects cancer at an early stage and allows doctors to perform procedures with minimal intervention in the patient's body. It is an invasive procedure, posing risks such as bleeding or perforation. Tumors outside the field of view may be missed.

FIBROBRONCHOSCOPY

The fibrobronchoscopy is a specialized form of endoscopy used to examine the airways and bronchi. It allows doctors to detect abnormal changes in the airways, such as tumors, inflammation, or scarring. Fibrobronchoscopy also allows taking tissue samples for biopsy, making it an im-

portant tool for diagnosing lung cancer. In addition, during this procedure, therapeutic manipulations can be performed, such as removing tumors, polyps, or foreign bodies from the respiratory tract, which makes this method not only diagnostic but also curative. The method is limited to the airways and can cause complications like bleeding or infection. Deep parenchymal lesions require alternative diagnostic approaches.

ANALYSIS OF SCIENTIFIC APPROACHES TO CLASSICAL METHODS OF CANCER DIAGNOSIS IN MODERN LITERATURE

Some authors also highlight certain advantages of classical methods of cancer diagnosis. Thus, Lennon et al.(30), in their study, noted that blood testing allows minimally invasive detection of molecular markers associated with cancer, which can be used for early diagnosis. That is especially effective when combined with imaging techniques such as PET-CT, which improves accuracy and reduces the number of unnecessary procedures. A blood test helps identify cancer before symptoms appear and increases the chances of successful treatment through early intervention. In addition, according to Paydary et al.(31), PET-CT is not used for the primary diagnosis of breast cancer, but it is effective in detecting metastases, especially in mediastinal, axial, and intrathoracic lymph nodes, where other methods may not be accurate enough. PET-CT is also useful for detecting distant metastases, especially in bones, where it has proven to be more accurate than bone scintigraphy. In addition, this method showed high accuracy in predicting the response to neoadjuvant chemotherapy and evaluating local-regional relapses in patients with elevated cancer markers.

Gillies and Schabath(32) emphasize the importance of using radiography and CT scans for early detection of malignancies, in particular, lung, pancreatic, and skin cancers. CT scans allow getting a three-dimensional image of the body with a detailed analysis of the size and location of tumors. With the use of radiomics (an analytical technology that converts images into quantitative data), this method improves the accuracy of tumor classification and allows distinguishing aggressive forms of cancer from more friendly neoplasms.

Endoscopy, according to Luo et al.(33), allows examining internal organs using a flexible probe with a camera, which results in detecting tumors at an early stage. Endoscopic ultrasound navigation (EUS) substantially improves the accuracy of tumor detection, especially in the gastrointestinal tract. According to the study, the use of endoscopic ultrasound biopsy (EUS-FNB) allowed accurately diagnosing endometrial cancer metastases in the rectum after a failed biopsy using conventional methods. This increases the accuracy of diagnostics due to the possibility of tissue sampling even in hard-to-reach places.

In turn, a puncture biopsy under the control of endoscopic ultrasound navigation allows obtaining high-quality tissue samples for pathological analysis with minimal invasiveness. This is especially important for tumors in hard-to-reach areas, such as lymph nodes or intra-abdominal organs. Facciorusso et al.(34) showed that EUS-FNB exceeds standard fine-needle aspiration (EUS-FNA) in terms of accuracy and sensitivity when taking tissue from abdominal lymph nodes, which improves diagnosis and avoids surgical intervention.

As supplemented by He et al.(35), ultrasound is a curricular method for diagnosing cancer, especially when examining tumors in the abdominal cavity. It is non-invasive and allows detecting tumors at an early stage. For example, endoscopic ultrasonography improves the accuracy of tumor diagnosis during gastroscopy, allowing not only the detection of neoplasms but also the accurate determination of their histological nature using a biopsy. The study showed that EUS helps to effectively diagnose pancreatic cancer even in cases where a surgical biopsy has failed.

Despite all the above-mentioned advantages of classical methods, they also have certain disadvantages, which is why their relevance began to decline. For example, radiography has some limitations because it is less sensitive to early changes in soft tissues and may not always detect small tumors. This method also does not provide accurate three-dimensional images, which limits the ability to assess tumors in complex areas of the body. In addition, X-rays have a potential health risk with frequent use, especially when examining a large number of sites. A puncture biopsy, although a high-precision method, may not give a complete picture of the tumor since the sample is taken from only one site, and it does not always reflect the

general characteristics of the neoplasm. In some cases, the resulting material may not contain enough cells for analysis, and the procedure, although minimally invasive, still has a certain risk of complications such as infections or bleeding.

Computed tomography, although it provides high-quality images, uses substantial doses of ionizing radiation, which can be dangerous with frequent examinations. CT scans are also not always effective for detecting small tumors in soft tissues, especially if these neoplasms have the same density as the surrounding tissues. In addition, injectable contrasts used to improve image quality can cause allergic reactions or kidney problems in patients with hypersensitivity.

Magnetic resonance imaging has limitations related to the duration of the procedure, which can take up to an hour, which causes discomfort in patients. MRI is also not suitable for people with metal implants or pacemakers due to exposure to the magnetic field. In addition, this method is more expensive than other diagnostic procedures and is not always available in small medical institutions.

Similarly, ultrasound has a limited ability to penetrate deep tissues or bones, making it less effective for diagnosing tumors in hard-to-reach areas of the body. The quality of ultrasound images may depend on the experience of the doctor performing the examination and on the physiological characteristics of the patient, such as obesity. Ultrasound does not always allow accurately assessing the size or boundaries of the tumor, which may require additional research. Positron emission tomography, despite its accuracy in determining metabolic activity, has disadvantages associated with the high cost of the procedure and the need to introduce radioactive substances. PET does not always provide an accurate anatomical image, so this method is often combined with CT or MRI scans for a more accurate diagnosis. Radioactive substances used during the examination have a limited shelf life, which can make it difficult to plan procedures.

Mammography, while the primary method for detecting breast cancer, may be less effective for women with dense breast tissue because tumors are harder to detect in such cases. In addition, this method uses ionizing radiation, which can be harmful with regular examinations. Mammography can also give false positive results, which leads to additional unnecessary examinations and patient anxiety. A blood test for cancer markers is not specific or sensitive enough to de-

tect cancer at an early stage since elevated levels of cancer markers can be caused not only by cancer but also by other pathologies or conditions. This method cannot accurately locate the tumor, so it is often used as an auxiliary tool in combination with other diagnostic methods.

Endoscopy is an invasive procedure that can cause some discomfort for the patient. Although the risk of complications is low, there is still the possibility of tissue injury, bleeding, or infection. In addition, endoscopy may not detect tumors that are out of the instrument's reach, so additional examination may be required for a complete picture. Fibrobronchoscopy, like other endoscopic techniques, is an invasive procedure that can cause complications such as bleeding or infection. In addition, this method is limited only to airway imaging and cannot cover other organs, which may require additional diagnostic procedures to fully assess the patient's condition.

As for the opinions of researchers, as noted by Gwak et al.(36), the fine needle aspiration biopsy (FNA) method also has its limitations. A study comparing FNA and core-biopsy (CNB) in the diagnosis of breast cancer determined that FNA, although a less invasive and faster method, has lower diagnostic accuracy compared to CNB. That can lead to erroneous or insufficiently accurate results, which in turn affects patient survival. The study established that patients diagnosed with FNA had substantially worse survival rates compared to those who underwent CNB. It is especially true for tumors that are difficult to palpate or located in hard-to-reach areas, making it difficult to obtain an accurate sample for analysis.

Ultrasound, in particular, endoscopic ultrasound diagnostics (EUs) with fine-needle aspiration, is a minimally invasive method, but it also has its limitations. For example, in a study that evaluated the effectiveness of EUS for lung tumor biopsy, which was performed by Chira et al.(37), it was determined that this method does not always provide enough samples for an accurate diagnosis in certain tumor locations, which may lead to patients having to undergo additional, more invasive procedures to obtain accurate results.

Thus, all the described methods of cancer diagnosis have both advantages and disadvantages (related to accuracy, safety, or availability), but they play a crucial role in early detection and confirmation of the diagnosis. Radiography, CT, MRI, and other techniques provide valuable informa-

tion but may require additional procedures to confirm the diagnosis. Current trends in oncology point to the need to introduce innovative technologies such as artificial intelligence, molecular diagnostics, and advanced imaging techniques that can improve the accuracy and effectiveness of diagnostics, reduce risks to patients, and make the cancer detection process faster and more accurate.

INNOVATIVE METHODS OF CANCER DIAGNOSTICS

The transition from classical methods of cancer diagnosis to innovative approaches is an important and relevant step for modern medicine. Traditional methods are often based on detecting already developed symptoms or tumors, which limits their effectiveness in the early stages of the disease. Innovative technologies open up new opportunities for earlier detection of cancer processes, which increases the chances of successful treatment and patient survival. Moreover, such methods are less invasive and provide more accurate results, shortening the time to diagnosis and reducing the burden on the patient's body. Table 2 shows a general list of innovative methods for cancer diagnosis with their characteristics.

LIQUID BIOPSY

As for the benefits of such diagnostic methods, liquid biopsy is an innovative and minimally invasive method for early cancer diagnosis based on the analysis of biomarkers derived from biological fluids such as blood, urine, or cerebrospinal fluid. The main advantage of this method is the ability to avoid surgical intervention since a simple blood sample is used for analysis. Blood samples contain circulating tumor cells (CTCs), circulating free DNA (cfDNA), and other biomarkers originating from tumor cells. This approach allows not only the detection of cancer at an early stage but also the monitoring of the progress of the disease during treatment, the evaluation of the effectiveness of therapy, and the tracking of relapses. The convenience and repeatability of sampling make liquid biopsy particularly attractive for regular monitoring of cancer patients, which contributes to an individualized approach to therapy and timely correction of treatment regi-

Table 2.

List of innovative cancer diagnostic technologies with their characteristics

Method	Characteristics
Liquid biopsy	A non-invasive diagnostic method that analyses circulating tumour DNA (ctDNA), circulating tumour cells (CTCs), and other biomarkers in body fluids (blood, saliva, urine)
Next-generation sequencing (NGS)	A genetic screening method used to analyse mutations in circulating tumour DNA.
miRNA analysis	Analysis of circulating microRNAs that regulate gene expression and may reflect the presence of a tumour at an early stage.
Exosome analysis	This is a method that involves detecting exosomes – small vesicles released by tumour cells into body fluids, exosomes contain DNA, RNA, and proteins of tumour origin, making them a promising source of biomarkers for early cancer diagnosis.
Genetic screening based on circulating tumour cell analysis (CTCs)	A method that allows isolating circulating tumour cells from the blood and analysing their genetic profile for early detection of mutations and prediction of treatment responses
Electrochemical detection technologies	Modern electrochemical platforms allow fast and accurate analysis of cancer biomarkers (such as DNA or RNA) using electrical signals.
Genetic screening using circulating free DNA (cfDNA)	Method that can detect mutations in the free DNA circulating in the patient's blood.

Source: compiled by the authors based on Soda et al.(38), Wu et al.(39), Chen and Zhao(40).

mens. The sensitivity of the method is constrained by the low concentration of ctDNA and CTCs in the early stages of cancer, potentially resulting in false negatives. Furthermore, liquid biopsy often cannot localize the anatomical origin of the tumor, and its implementation is limited by high costs and restricted availability in clinical settings.

NEXT-GENERATION SEQUENCING (NGS)

Next-generation sequencing (NGS) is an advanced genomic analysis technology that allows examining the tumor genome in detail with high accuracy and depth. Due to its ability to analyze a huge number of genetic changes simultaneously, NGS can detect rare mutations, genetic rearrangements, and other abnormalities in the DNA of tumor cells that may be associated with cancer development. This technology is useful for detecting oncogenic drivers in the early stages of disease development, even before the appearance of clinical manifestations. An important advantage of NGS is its ability to simultaneously analyze multiple genes or even complete genomes, making this method an effective tool for conducting personalized medicine. Based on the obtained genomic data, targeted therapies can be selected that affect specific genetic mutations in tumors, which substantially increases the effectiveness of treatment. Despite its diagnostic power, NGS remains costly and time-consuming. The analysis requires advanced bioinformatic tools and expert interpretation, especially since

some mutations may be benign or of uncertain significance. Variability in lab protocols may also affect standardization and reproducibility (48, 49).

MICRORNA (MIRNA) ANALYSIS

MicroRNA analysis (miRNA) is becoming increasingly popular as a method for early cancer diagnosis due to the ability of these molecules to regulate gene expression. MicroRNAs are short non-coding RNA molecules that can change in response to tumor development. Their stability in body fluids, such as blood or urine, makes them easy to analyze because they are not subject to rapid decomposition. Analysis of miRNA profiles allows identifying specific molecular signatures that correlate with the presence of certain types of cancer. Thus, this method allows you to diagnose the disease at an early stage, which increases the chances of successful treatment. In addition, miRNA analysis can be used to monitor disease progress and assess response to therapy, making this approach a universal tool in cancer practice. Challenges include low concentrations of miRNA in samples, potential overlaps with other diseases, and variability in analytical platforms. The lack of standardized protocols leads to inconsistent results across laboratories. Sample preparation, such as avoiding adapter dimers in sequencing, remains technically demanding.

EXOSOME ANALYSIS

Exosome analysis is the latest approach to early cancer diagnosis, based on the examination of microvesicles secreted by tumor cells. Exosomes are small membrane vesicles containing a wide range of biological molecules, including DNA, RNA, proteins, and other components that can indicate the presence of tumor processes in the body. The peculiarity of exosomes is that they are secreted by all types of cells, including cancer cells, and can be easily isolated from various biological fluids, such as blood, urine, or saliva. Due to their ability to carry information about the tumor genome, exosomes can not only detect cancer at an early stage but also characterize its genetic profile. This is important for selecting the optimal therapy that targets specific molecular targets of the tumor, monitoring the effectiveness of treatment, and predicting relapses. Exosome isolation is technically complex due to their small size and low concentration in fluids. Moreover, normal cells also release exosomes, which complicates specificity. Standardization of protocols and reproducibility of results remain substantial barriers to clinical application.

CIRCULATING TUMOR CELLS ANALYSIS

Genetic testing based on the analysis of circulating tumor cells (CTC) opens new perspectives for early cancer diagnosis and monitoring its course. These cells, which have detached from the primary tumor and entered the bloodstream, can be isolated and analyzed to detect molecular cancer markers.

Genetic screening based on the analysis of CTC opens new perspectives for early cancer diagnosis and monitoring its course. These cells, which have separated from the primary tumor and entered the bloodstream, can be isolated and analyzed to detect molecular signs of cancer. CTC analysis can detect cancer at an early stage, determine the potential of the tumor to metastasize, and predict the course of the disease. This technology is useful for evaluating the response to therapy in real time, as changes in the number and characteristics of CTC may indicate the effectiveness of treatment or the need for its correction. In addition, CTC-based screening is promising for

assessing the risk of relapse after successful treatment, allowing doctors to respond quickly to changes in the patient's condition. CTC are often present in extremely low numbers, especially in early-stage cancers, reducing detection sensitivity. The process of CTC isolation and genomic profiling requires specialized equipment and expertise. Furthermore, not all detected cells are malignant or metastatically relevant.

ELECTROCHEMICAL DETECTION TECHNOLOGIES

Electrochemical cancer detection technologies are a promising direction in early diagnosis due to their high sensitivity and speed. Electrochemical sensors can be configured to detect specific biomarkers, such as proteins, DNA, RNA, or metabolites associated with cancer development. These sensors work by measuring changes in electrochemical signals that occur when interacting with biomarkers and can be used to analyze blood, urine, or saliva samples. The advantage of electrochemical detection is its ability to quickly and accurately detect the presence of tumor biomarkers even at low concentrations, making this method effective for mass screening of the population. In addition, electrochemical sensors are relatively cheap and easy to use, which allows implementing them in general practice, especially in cases where regular monitoring of the patient's condition is required. But the sensitivity may vary depending on biomarker concentration and matrix complexity. Low abundance biomarkers may be undetectable, leading to false negatives. External contaminants and a lack of validated markers for some cancers further limit diagnostic reliability.

CIRCULATING FREE DNA ANALYSIS

Genetic screening of circulating free DNA (cfDNA) is one of the most promising methods for noninvasive cancer diagnosis. Circulating free DNA are fragments of genetic material released by tumors and other cells into the bloodstream and may contain mutations and other genetic changes associated with cancer. By analyzing cfDNA, we can detect even minor genetic abnormalities, making it particularly useful for early diagno-

sis of the disease. In addition, this method allows tracking the progress of the tumor process, evaluating the effectiveness of treatment, and predicting the risk of relapse. Modern technologies enable the analysis of cfDNA with high accuracy, detecting mutations in real time, allowing doctors to quickly respond to changes in the patient's condition and adjust treatment strategies according to individual needs. The sensitivity of the method is affected by low cfDNA levels in early-stage cancers. Moreover, cfDNA may originate from both malignant and non-malignant cells, which complicates interpretation. Like NGS, this method requires sophisticated platforms and trained personnel, which limits its accessibility.

STUDYING RESEARCH APPROACHES TO CLASSICAL ONCOLOGICAL DIAGNOSTICS: AN ANALYTICAL REVIEW

The researchers also note the benefits that innovative technologies provide in the early stages of cancer diagnosis. Thus, according to Choucair et al.(41) and Horgan et al.(42) liquid biopsy has several key advantages in early cancer diagnosis. It is minimally invasive because it is performed using a blood test, which reduces the patient's discomfort compared to traditional methods such as a tissue biopsy. This allows regularly monitoring the progress of the disease and adapting therapy in real time, providing a more accurate and personalized treatment strategy. A liquid biopsy can also detect mutations at a very early stage of cancer, which increases the chances of timely intervention and improved prognosis for patients. Next-generation sequencing (NGS), as noted by García-Silva et al.(43), allows rapid and accurate detection of a wide range of cancer-related genetic changes based on tumor DNA analysis. The main advantage of NGS is its high sensitivity and accuracy, which allows identifying even rare genetic mutations that are important for choosing a personalized treatment. This substantially reduces the time required to determine the best therapy and increases the effectiveness of treatment, which improves the prognosis for patients.

The miRNA analysis has proven to be a powerful tool for early diagnosis, as miRNAs can function as biomarkers for various types of cancer. The high specificity and sensitivity of this method make

it possible to effectively identify tumors at an early stage. Furthermore, according to Tomar et al.(44), miRNA analysis does not require invasive procedures and can be used to dynamically monitor disease progress and response to therapy, making this approach convenient for patients and physicians.

García-Silva et al.(43) add that exosome analysis has substantial diagnostic potential since exosomes can transmit information about genetic and molecular changes in tumors. Their analysis allows tracking the dynamics of tumor processes and predicting the response to treatment. The advantage of this method is its non-invasiveness, which allows regular studies to be conducted without harm to the patient, as well as its high sensitivity to detect biomarkers in the early stages of the disease.

Genetic screening based on the analysis of CTC allows tracking the presence and dynamics of the tumor process in the patient's body. The main advantage of this method is that it allows detecting the tumor at a very early stage and monitoring its development without the need for invasive procedures, which ensures better treatment management and timely adjustment of therapy(45). Electrochemical detection technologies, as emphasized by Ignatiadis et al.(46) allow the detection of cancer biomarkers with high sensitivity and speed, which is especially important for early diagnosis. These technologies are affordable and cost-effective, making them attractive for mass use. They provide accurate detection and allow monitoring the tumor process in real time, which increases the likelihood of successful treatment in the early stages.

Genetic screening using cfDNA allows non-invasive detection of genetic changes occurring in the tumor at a very early stage; this allows not only the establishment of a diagnosis but also the tracking of the effectiveness of treatment and the development of resistance to therapy. The advantage of this approach, according to Guibert et al. (47), consists in its non-invasiveness, which allows regular studies to monitor the tumor process and timely adjustment of treatment.

As with all methods, the above ones have certain disadvantages that are worth highlighting. Despite its substantial potential, liquid biopsy has several limitations. One of the main disadvantages is the low concentration of CTCs or cfDNA in the blood, especially in the early stages of the disease. This can make cancer detection difficult be-

cause there is a possibility of false-negative results due to an insufficient number of biomarkers in the sample. In addition, it is sometimes difficult to determine the exact source of the tumor since a liquid biopsy does not always enable the unambiguous identification of the organ or tissue where the disease occurred. Another problem is the high cost of conducting such studies and limited availability in a number of medical institutions. NGS also has its drawbacks, despite its power and accuracy. One of the main problems is the high cost of research, which limits its widespread use, especially in health systems with a limited budget. In addition, the analysis of data obtained using NGS requires highly qualified specialists since it involves a complex interpretation of genomic changes. Sometimes the detected mutations can be neutral or unrelated to cancer, which makes it difficult to interpret the results and choose the appropriate therapy. An important disadvantage is also the need for substantial time and material resources for analysis, which may not allow using this method for urgent diagnostics.

The miRNA analysis has certain limitations that may affect its effectiveness in cancer diagnosis. Although microRNAs are stable in the blood, their quantity in samples can be very low, making the detection difficult. Moreover, many types of miRNAs can be specific to various diseases, not just cancer, which makes it difficult to accurately diagnose. There is also the problem of method standardization since different laboratories may use different platforms and methods for analysis, which can lead to variability in the results. In addition, the process of obtaining and analyzing data requires sophisticated equipment and experienced specialists, which limits the availability of the method in some clinical settings. Exosome analysis also has numerous disadvantages. The main problem is the complexity of their isolation since exosomes are very small and exist in low concentrations in biological fluids. This makes their isolation and subsequent analysis a technically complex and often expensive process. Another problem is that exosomes can be secreted not only by cancer cells but also by normal cells of the body, which makes it difficult to identify those exosomes that are of oncological origin. In addition, standardization of methods for examining exosomes remains a problem, which can lead to

discrepancies in results between different laboratories and make it difficult to interpret the results.

Despite the prospects of using CTCs for cancer diagnosis, this method has its drawbacks. Firstly, the number of CTCs in the blood can be extremely low, especially in the early stages of the disease, which reduces the sensitivity of the test and can lead to false negative results. Secondly, CTC isolation and analysis are technically complex processes that require high-end equipment and qualified specialists, making this method expensive and difficult to access for many hospitals. In addition, interpreting the results can be difficult, since not all circulating cells contained in the sample may be oncogenic or capable of metastasizing. Electrochemical cancer detection technologies, while promising, have their drawbacks. One of the main disadvantages is that their sensitivity may vary depending on the type of biomarkers used for analysis. Some biomarkers may be present in too low concentrations to be detected by electrochemical sensors, which can lead to false negative results. In addition, these methods may be affected by external factors, such as contamination of the sample or the presence of other chemicals in the biological fluid, which may affect the accuracy of measurements. Another disadvantage is that for many types of cancer, electrochemical biomarkers have not yet been fully identified, which limits the use of these technologies in practical diagnostics.

Genetic screening with cfDNA has several substantial drawbacks. Firstly, the concentration of cfDNA in the blood can be very low, especially in the early stages of the disease, which makes it difficult to detect. Secondly, cfDNA can originate not only from tumor cells but also from normal cells, which complicates interpreting the results and can lead to false positive results. In addition, the method requires highly sensitive equipment and experienced specialists for analysis, which increases the cost of testing and limits the availability of the method. Another problem is the difficulty of identifying small genetic changes or rare mutations that may be important for predicting the effectiveness of therapy or the development of drug resistance.

Researchers also highlight certain disadvantages of such methods. NGS has substantial advantages in speed and scale but has numerous disadvantages that limit its effectiveness in clinical practice. One of the main problems is the high error

rate, especially when detecting rare mutations or low-level genetic variants. This reduces the sensitivity and accuracy of the method, which can affect the results of diagnosis and prognosis. Moreover, NGS technology is expensive and requires substantial financial resources to be implemented in broad clinical practice. Difficulties in standardizing protocols and interpreting data in different laboratories also pose a serious obstacle to its widespread use. These problems often lead to different variants of results depending on the laboratory or the specific methodology used for sample processing(48, 49).

MiRNA analysis faces challenges associated with sample preparation, especially when it comes to small amounts of RNA in samples. For example, one of the most common problems is the formation of adapter dimers when preparing libraries for sequencing, which can substantially complicate analysis and reduce the amount of reliable data. This is especially true when working with exosomes, where the amount of RNA may not be sufficient for full-fledged research. Even when using optimized protocols, the problem remains, which limits the use of this technology in routine clinical practice. In addition, due to biological variability, analysis of the results may require additional stages of validation and retesting to confirm accuracy(50).

Exosome analysis as a diagnostic approach also faces numerous technical and methodological obstacles. This is mainly due to difficulties in isolating enough exosomes from body fluids for reliable analysis. Standardization of methods for isolating and quantifying exosomes is still an open question, which creates obstacles to the widespread use of this technology in clinical settings. In addition, the need for sophisticated analysis equipment may also limit the availability of this method for less affluent hospitals and laboratories. Another problem is the diversity of biomarkers secreted by exosomes, which can vary depending on the stage of the disease or the patient's biological condition, which requires careful selection of tests for specific clinical situations(51). Electrochemical detection technologies, despite their potential for mass applications due to their simplicity and availability, face accuracy and sensitivity challenges. These technologies require further improvements to provide stable and reliable results in the early detection of cancer biomarkers. Limitations also apply to the accuracy of measurements at low concentrations of biomarkers, which

can lead to false-positive or false-negative results in patients with early stages of the disease. This limits the use of these technologies as the main diagnostic tool, especially in complex cases or for monitoring the progress of therapy(46).

Despite the existing shortcomings of innovative methods of cancer diagnosis, they should be chosen in contrast to the classic ones since they provide much greater accuracy and sensitivity. Innovative approaches, such as liquid biopsy, next-generation sequencing, or circulating free DNA analysis, can detect cancer at the molecular level even before clinical symptoms appear, substantially increasing the chances of successful treatment. In addition, such methods allow continuous monitoring of the disease without the need for repeated invasive procedures, allowing quick adaptation of therapy to changes in the tumor. Notably, the innovative technologies allow personalizing treatment based on individual genetic characteristics of the tumor, which makes treatment more effective and less aggressive for the patient.

COMPARATIVE ANALYSIS OF CLASSICAL AND INNOVATIVE CANCER DIAGNOSTIC METHODS

Classical diagnostic methods are largely dependent on anatomical or morphological changes and are thus most effective in detecting established tumors. For instance, radiography and mammography are effective in identifying solid masses, yet their sensitivity sharply decreases for small lesions or early-stage neoplasms, especially in soft tissues or dense anatomical areas. Similarly, biopsy-although definitive for histological confirmation-depends on the tumor's visibility or palpability, limiting its utility in subclinical disease. In contrast, innovative methods such as liquid biopsy, cfDNA analysis, and miRNA profiling detect molecular changes long before morphological alterations occur. These techniques enable the identification of oncogenic mutations, epigenetic changes, and circulating tumor components (CTC, cfDNA) even at the asymptomatic stage. As such, they offer a critical advantage in pre-symptomatic screening and early therapeutic intervention, thereby improving prognosis and enabling minimally invasive disease monitoring.

Traditional techniques like endoscopy, fibrobronchoscopy, and biopsy are inherently invasive,

involving physical insertion of instruments or tissue extraction. Though effective, these methods pose risks, including infection, bleeding, and patient discomfort, and they often require anaesthesia or post-procedural recovery.

Innovative diagnostics, on the other hand, emphasize minimal invasiveness. Most are blood- or fluid-based (liquid biopsy, miRNA analysis, exosome profiling), significantly reducing procedural risk and enabling frequent repetition. This is particularly advantageous for longitudinal monitoring, real-time treatment evaluation, and adjustment of therapeutic regimens, making the diagnostic process safer and more tolerable for patients undergoing extended care.

While classical imaging methods (CT, MRI, PET) provide detailed anatomical insights, they often lack specificity and may not distinguish between benign and malignant changes without confirmatory biopsy. Furthermore, blood-based tumor markers (e.g., PSA, CEA, AFP) used in traditional protocols can yield false positives due to elevation in benign conditions. In contrast, innovative tools such as NGS, cfDNA sequencing, and CTC genomic profiling offer high analytical specificity. They enable precise molecular characterization of tumors, identification of actionable mutations, and assessment of treatment resistance pathways. This facilitates a more nuanced understanding of tumor biology, supporting the shift from population-based to individualized oncological care.

Classical methods are widely available and relatively inexpensive. Their infrastructural and technological requirements are well-established, making them suitable for both high- and low-resource clinical settings. Their cost-effectiveness and ease of interpretation explain their sustained use in mass screening programs and public healthcare systems.

Innovative technologies, by contrast, often require specialized equipment, highly skilled personnel, and substantial financial resources. Techniques like NGS, exosome isolation, and electrochemical detection are not yet uniformly accessible and remain concentrated in advanced cancer centers and research institutions. This disparity limits the global scalability of these diagnostics, though ongoing technological refinements and cost reductions may facilitate broader implementation in the future.

In conclusion, classical methods continue to serve as essential tools in cancer diagnostics due to their accessibility, established reliability, and infrastructural readiness. However, innovative diagnostic modalities provide unparalleled advantages in early detection, precision medicine, and longitudinal patient management. Rather than replacing traditional approaches, these methods are most effective when used complementarily, forming an integrated diagnostic strategy that aligns with contemporary oncological care. Future efforts should focus on overcoming technical, financial, and regulatory barriers to ensure equitable access to advanced diagnostics worldwide.

CONCLUSION

The study established that innovative methods of early cancer diagnosis, such as genetic screening, liquid biopsy, and microRNA analysis, have substantial potential to improve early-stage cancer detection. These methods allowed identifying tumor processes long before the disease manifested itself clinically, which increased the chances of successful treatment. It was confirmed that genetic screening can detect mutations in cfDNA, which allows predicting the development of cancerous tumors. Liquid biopsy showed high sensitivity in detecting CTC and cfDNA, which allowed monitoring the condition of patients during treatment, assessing the progress of the disease, and detecting relapses. MiRNA analysis, in turn, has proven useful in the diagnosis of various types of cancer since these molecules regulate the expression of genes that are an important marker of the presence of a tumor. However, the low concentration of microRNAs in the samples may complicate the accuracy of diagnosis.

The results showed that innovative methods substantially outperformed classical approaches in terms of such qualitative indicators as sensitivity, specificity, and the possibility of non-invasive monitoring of patients' conditions. This opened up new opportunities for a personalized approach to treatment and early intervention, which is critical to improving the survival rate of cancer patients. Therewith, the study also identified certain limitations. One of the main drawbacks was that some methods, such as liquid biopsy, required high-precision equipment and were associated

with high costs, which limited their availability in less developed healthcare settings. In addition, the problem of low concentrations of biomarkers, in particular, CTCs and cfDNA, required further research to improve the sensitivity of the methods.

As for the limitations of this study, the main aspect is that it was theoretical, so it was impossible to practically check the advantages of innovative diagnostic methods. Therefore, future research should focus on several specific directions: (1) conducting comparative clinical trials to empirically assess the diagnostic accuracy of innovative methods relative to classical ones; (2) developing integrated diagnostic protocols that combine anatomical imaging with molecular screening to maximize diagnostic yield; and (3) exploring cost-effective adaptations of molecular diagnostics for broader implementation in under-resourced healthcare systems. Such investigations will help establish a robust evidence base for integrating next-generation diagnostics into routine oncological practice.

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Sažetak

Inovativne metode rane dijagnoze raka: od genskog probira do tekućinske biopsije

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Cilj: Cilj studije je istražiti prednosti i nedostatke tradicionalnih i inovativnih metoda dijagnosticiranja raka. Studija uključuje pregled koncepta raka, njegovih vrsta i uzroka.

Ispitanici i metode: Preglednim radom analizirane su prednosti i nedostaci klasičnih metoda dijagnostike raka poput radiografije, punkcijske biopsije, kompjuterizirane tomografije, magnetske rezonancije, ultrazvuka, pozitronske emisijske tomografije, mamografije, krvnih testova za markere raka, endoskopije i fibrobronhoskopije. Rad također ispituje inovativne metode dijagnostike patologije raka poput tekućinske biopsije, sekvenciranja sljedeće generacije, analize mikroRNA, analize egzosoma, genskog probira temeljenog na elektrokemijskom otkrivanju cirkulirajućih tumorskih stanica i genskog probira korištenjem slobodne DNA u cirkulaciji.

Rezultati: Studija otkriva da su konvencionalne metode invazivne i rizične, a moderne tehnologije pouzdano otkrivaju molekularne markere kako bi se rak otkrio u ranoj fazi. Tekućinska biopsija korisna je u praćenju napredovanja tumorske bolesti bez operacije. Sekvenciranje sljedeće generacije može pronaći rijetke genske mutacije, što pomaže u prilagođenom liječenju. Analiza mikroRNA i egzosoma pruža molekularne markere agresivnosti tumora i odgovora na liječenje.

Zaključak: Glavno ograničenje najnovijih metoda je njihova visoka cijena i potreba za specijaliziranom opremom i stručnim osobljem, što smanjuje dostupnost takvih tehnologija.

KLJUČNE RIJEČI: *onkologija; detekcija bolesti; najnovije tehnologije; predviđanje bolesti; markeri raka*