ANALYSIS OF EFFECTIVE METHODS FOR DIAGNOSING INVASIVE DUCTAL CARCINOMA OF THE BREAST IN THE EARLY STAGES

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Abstract. *This study analyzes effective and innovative methods for the early diagnosis of invasive ductal carcinoma (IDC) of the breast. Its relevance stems from the high aggressiveness of IDC and the high rate of late-stage detection in Uzbekistan. A systematic analysis was conducted of 40 international scientific sources from 2019–2025, including GLOBOCAN 2024–2025 data. Traditional mammography lacks sufficient sensitivity for detecting tumors in dense breast tissue, whereas contrast-enhanced mammography (CEM) and digital breast tomosynthesis (DBT) increase diagnostic accuracy to over 90%. Furthermore, applying artificial intelligence (AI) algorithms in the diagnostic process reduces radiological errors by up to 20% and, through early diagnosis, can achieve a five-year survival rate of up to 99%. Integrating modern imaging and AI technologies into national oncology screening programs is scientifically justified as the most effective strategy to reduce IDC-related mortality.*

Keywords: *invasive ductal carcinoma, early diagnosis, contrast-enhanced mammography (CEM), digital breast tomosynthesis (DBT), artificial intelligence (AI), oncological screening, imaging methods, oncology in Uzbekistan*

Introduction. Breast cancer (BC) remains one of the most pressing issues in modern oncology, consistently ranking first in morbidity and mortality among women worldwide [12, 32]. Recent statistical analyses (GLOBOCAN 2024–2025) indicate that incidence rates are increasing year by year, and if current diagnostic trends remain unchanged, mortality is projected to rise by another 40% by 2050 [12]. Invasive ductal carcinoma (IDC) is the most common form (75–80%) of malignant breast tumors, distinguished not only by its high metastatic potential but also by its biological heterogeneity [4, 27, 35].

Within the oncology service of Uzbekistan, BC occupies the leading position among all oncological diseases, with over 4,000 new cases registered annually [8]. The most concerning aspect is that approximately 45–50% of cases detected in the country still correspond to stages III and IV, which significantly reduces the five-year survival rate [8, 13]. Yet, when IDC is diagnosed at stage I, the probability of complete recovery reaches 99% [4].

The main obstacle in diagnosis is the "dense breast" syndrome, which reduces the sensitivity of traditional mammography to 40–50% [36, 38]. This leads to the "masking effect," causing clinically significant invasion foci to be missed [26, 36]. Therefore, filling this "diagnostic gap" by integrating contrast-enhanced mammography (CEM), digital breast tomosynthesis (DBT), and artificial intelligence (AI) algorithms is an urgent requirement of today [25, 26]. Studies from 2025 show that photon-counting CT and nanotechnological visualization methods can detect micro-carcinomas as small as 0.2 mm [21, 25].

Aim. The aim of this study is to conduct a comprehensive analysis of traditional and innovative methods for diagnosing invasive ductal carcinoma in early stages, to compare their effectiveness, and to provide a scientific basis for new diagnostic paradigms in modern oncology.

Methods. This study was conducted based on a comparative analysis of the global and national situation regarding the early detection of invasive ductal carcinoma (IDC) of the breast. The work followed the stages outlined below:

1. Information search strategy and source management: Fundamental data for the study were selected from reputable databases such as PubMed, Scopus, and Google Scholar, primarily from academic publications in English. The search used combinations of terms reflecting diagnostic accuracy, including "contrast-enhanced mammography," "AI in breast cancer detection," and "photon-counting CT."

2. Data selection and filtering (inclusion/exclusion criteria): To ensure the scientific novelty of the work, the main focus was placed on the last five years (2019–2025). A total of 40 literature sources were selected, of which 25% are articles on the latest technological advances from 2024–2025. Only materials relevant to the early diagnosis of IDC (stages 0–II) with reliable clinical results were included in the analysis, while general oncological information only indirectly related to the topic was excluded.

3. Personal analysis and comparison methodology: To study the effectiveness of the selected diagnostic methods (CEM, DBT, MRI, and AI), a method of comparing their sensitivity and specificity indicators was used. Additionally, statistical reports from the Uzbekistan oncology service (2019–2024) were compared with global GLOBOCAN trends to identify diagnostic gaps in national oncology.

4. Ethical principles and citation: As the study is a review, clinical trials were not required. All scientific ideas and statistical data used were cited based on the Vancouver style, preserving the copyright of the authors, thereby ensuring academic honesty.

Results. *Structural-Histopathological and Molecular-Genetic Analysis of Invasive Ductal Carcinoma.* Analysis of the obtained data shows that invasive ductal carcinoma (IDC) of the breast is characterized by the infiltration of the stroma and adipose tissue by epithelial cells of the milk ducts after breaking through the basement membrane [5, 27]. Statistically, this pathology accounts for 75–80% of all breast tumors and exhibits a high degree of clinical and morphological polymorphism [37, 38].

According to histopathological analyses, the degree of malignancy (G-grade) is determined based on nuclear atypia, tubule formation, and mitotic activity [22]. The study found that the presence of ductal components alongside micropapillary structures significantly increases the likelihood of lymphogenous metastasis [5, 23]. As a result of molecular-biological stratification, four main phenotypes of IDC (Luminal A/B, HER2-positive, and triple-negative) were identified, each distinguished by hormone receptor (ER, PR) and HER2 status [20, 37]. Furthermore, it was confirmed that at the genetic level, BRCA1/2 mutations and changes in micro-RNA expression are key mechanisms of disease development [19, 33].

Diagnostic Capabilities and Comparative Analysis of Traditional Visualization Technologies. Comparative analysis of visualization technologies shows that the effectiveness of digital mammography in detecting invasive ductal carcinoma (IDC) remains directly dependent on breast tissue density (ACR criteria) [28, 29]. The study found that in women with dense breast tissue, the standard mammography method fails to fully visualize tumor foci ("masking effect"), leading to an increased proportion of false-negative diagnostic conclusions [17, 34].

Three-dimensional digital tomosynthesis (DBT) technology demonstrated high performance in solving this problem. The DBT method, through layer-by-layer (tomographic) imaging of tissues, more accurately identifies spiculation of tumor margins characteristic of invasive processes and clusters of microcalcifications [3, 14]. According to statistics, it was confirmed that the use of tomosynthesis technology increases the detection rate of invasive tumors by 15% to 20% compared to traditional 2D mammography [3]. Simultaneously, ultrasound examination (US) retained its

significance as an additional diagnostic tool in the group of young women with predominantly glandular tissue [28, 34].

The highest sensitivity rate (90-95%) was observed with magnetic resonance imaging (MRI). MRI proved to be the gold standard for identifying not only the primary tumor focus of IDC but also its multifocal growth pattern and anatomical boundaries [10, 15]. Furthermore, recent research shows that contrast-enhanced mammography (CEM) is several times superior to traditional methods in detecting pathological neovascularization (formation of new blood vessels) within the tumor [3, 28].

Diagnostic Method	Sensitivity	Specificity	Main Advantage
Traditional Mammography	45-65%	75-80%	Inexpensive and widely available
Digital Tomosynthesis (DBT)	80-85%	85-90%	Clearly shows tissue layers
Contrast-Enhanced Mammography (CEM)	90-95%	92-96%	Detects vascular pathology
Artificial Intelligence (AI) + CEM	96-98%	95-97%	Minimizes diagnostic errors
MRI (with Contrast)	94-99%	85-90%	Highest accuracy level

Table analysis shows that compared to traditional mammography, CEM and artificial intelligence (AI) technologies can increase the sensitivity rate by 30–40%. This scientifically substantiates the priority of these methods for detecting IDC at a microscopic level.

Prognostic Significance of Molecular-Genetic Profiling and Innovative Biomarkers. The molecular-genetic part of the study revealed that the expression of specific proteins and indicators of genetic mutations are of crucial diagnostic importance in assessing the biological aggressiveness of invasive ductal carcinoma (IDC) [22, 27]. The obtained data show that the expression levels of estrogen (ER), progesterone (PR), and HER2 receptors, as well as the Ki-67 proliferative index, serve as standard markers for classifying IDC into four main molecular subtypes (Luminal A, Luminal B, HER2-positive, and triple-negative) [5, 6].

When analyzing "liquid biopsy" as an innovative diagnostic method, it was confirmed that an increase in the concentration of circulating tumor DNA (ctDNA) in blood plasma is observed several months before the tumor volume becomes apparent with traditional visualization methods (mammography or MRI) [19, 20]. It was also found that disruption of micro-RNA (miRNA) profiles and epigenetic methylation processes cease the functional activity of tumor suppressor genes, manifesting as an early indicator of the invasive process [23, 33].

In assessing genetic predisposition, along with BRCA1 and BRCA2 mutations, it was observed that multigene panels like Oncotype DX and MammaPrint can calculate the likelihood of metastasis with mathematical accuracy by analyzing the activity of dozens of genes in the tumor tissue [1, 40]. Using these tests to create an individual biological profile for each patient achieved an accuracy of 85–90% [18, 23].

The Transformative Role of Digital Technologies and Artificial Intelligence in IDC Screening. The study results showed that digital technologies and the artificial intelligence (AI) ecosystem are fundamentally transforming traditional visual analysis methods in detecting invasive ductal carcinoma (IDC) of the breast [26, 35]. It was found that processing vast amounts of diagnostic data (Big Data) streams using neural networks statistically significantly reduces diagnostic errors [36].

1. Diagnostic Effectiveness of Algorithms:

The average accuracy coefficient (AUC) of deep learning models in analyzing mammography and MRI scans ranged from 0.92 to 0.96 [7, 9]. This indicator not only competes with the conclusions of experienced radiologists but was also confirmed to reduce false-negative results by 18–22% when used as a "second opinion" [2, 6].

2. Digital Pathology and Histological Classification:

Convolutional neural networks (CNNs) automatically identified microscopic invasion boundaries of tumor cells and the degree of nuclear atypia in histopathological specimens [6]. AI demonstrated 30% higher accuracy than the human eye in calculating mitotic activity per square millimeter using digital scanning systems, allowing precise determination of the malignancy grade (G-grade) of the tumor [2, 36].

3. Multimodal Integration and Tomosynthesis:

It was found that synthesizing digital breast tomosynthesis (DBT) data with AI algorithms eliminates the "visual noise" (masking effect) caused by the overlapping of breast tissues [26]. This combination was reported to increase the detection rate of early-stage (T1a, T1b) tumor foci by 25–27% compared to traditional 2D mammography [7].

4. Radiogenomics and Phenotypic Prediction:

One of the most innovative outcomes is the formation of radiogenomics models. It was observed that artificial intelligence can predict the molecular-genetic characteristics (e.g., HER2 status or Ki-67 index) of a tumor with 88% accuracy based on its visual texture (imaging features) without invasive procedures [2, 9].

Innovative and Promising Technologies in Invasive Ductal Carcinoma Diagnosis. In the final stage of the study, the effectiveness of hybrid and nanotechnological solutions in the diagnosis of invasive ductal carcinoma (IDC) was analyzed. The obtained data show that the transition from traditional visualization methods to hybrid technologies elevates diagnostic accuracy to a new level [21, 25].

1. Photon-Counting Computed Tomography:

It was found that this technology dramatically improves image spatial resolution compared to traditional CT. Results showed that this method allows identification of micro-invasion foci and calcifications in the breast as small as 0.2 mm [25, 31]. At the same time, its effectiveness in dividing the histological structure of tissues into virtual layers while reducing radiation dose was proven [25].

2. Smart Biopsy Systems:

The possibility of determining the malignancy level of tissue samples in real-time during the biopsy procedure itself, using needles equipped with optical sensors, was studied [21, 30]. It was noted that integrating Raman spectroscopy and optical coherence tomography (OCT) technologies significantly reduces the number of re-excisions by precisely defining the invasion boundaries of IDC during surgery [30, 31].

3. Nanotechnological Visualization and MSOT:

The use of nanomarkers that bind to specific receptors such as HER2 or EGFR on tumor cells was confirmed to illuminate cellular-level activity before the macroscopic formation of the tumor [2, 21]. Additionally, multispectral optoacoustic tomography (MSOT) demonstrated high sensitivity in measuring the level of hypoxia (oxygen deficiency) and metabolic activity within the tumor [25, 30].

Epidemiological Analysis and Correlation of Survival Rates with Diagnostic Timing. Analysis of epidemiological data showed that invasive ductal carcinoma (IDC) remains the most common form globally, accounting for approximately 80% of breast cancer pathologies [4, 11]. During the study, the following statistical correlations were identified between the time of disease detection and patient survival rates:

1. Indicators at Early Stages (Stages I–II): In countries with well-developed screening systems, the detection rate of IDC at early stages is high, maintaining the five-year survival rate at a maximum range of 90% to 99% [12, 13].

2. Indicators at Late Stages (Stages III–IV): Conversely, in Central Asia and particularly in Uzbekistan, the pathology is often identified at advanced stages, leading to increased mortality and a significantly worsened prognosis [8].

3. Correlation with Metastasis and Tumor Size: It was confirmed that the probability of complete recovery is highest when the tumor size is less than 2 cm and it has not spread to lymph

nodes [4, 11]. Survival was observed to drop to 75–84% when invasion reached regional lymph nodes, and to 25–30% in the presence of distant metastases [12, 13].

4. Age and Biological Subtypes: According to projections for 2024–2025, the frequency of aggressive subtypes of IDC (triple-negative and HER2-positive) is increasing among younger patients [8, 11].

Discussion. *Structural-Histopathological and Molecular-Genetic Analysis of Invasive Ductal Carcinoma.* The study results show that in the early pathogenesis of IDC, disruption of cell differentiation not only leads to the formation of the primary tumor but also increases the risk of systemic micrometastases [18, 39]. A debatable aspect is that tumor microarchitecture and destructive changes in the extracellular matrix enhance the aggressiveness of cancer cells and increase their resistance to therapeutic agents [37, 39].

Currently, digital pathology platforms and machine learning algorithms play an important role in eliminating human-related errors associated with traditional microscopic analysis [24, 35, 38]. These technological advances enable accurate classification of IDC at an early stage by integrating histopathological indicators with molecular biomarkers [36, 40]. Relying solely on morphological changes is insufficient; combining histopathological data with modern genetic profiling allows predicting the long-term prognosis of the disease with mathematical precision.

Diagnostic Capabilities and Comparative Analysis of Traditional Visualization Technologies. The obtained results confirm that limiting the diagnosis of IDC to a single visualization method can lead to serious consequences, especially in complex clinical cases. Modern oncological analyses show that the limitations of traditional mammography (against the background of dense tissue) are successfully overcome through innovative technologies such as DBT and CEM [3, 14]. The tomosynthesis capability of layer-by-layer imaging minimizes overlapping of tumor structures, allowing more precise planning of tumor volume before surgery.

Although MRI has very high sensitivity, a debatable aspect is its low specificity, which often leads to false-positive results and unnecessary biopsies [14, 15]. Therefore, CEM technology is considered a more economically affordable and practically convenient alternative to MRI. CEM visualizes invasion areas through the neovascularization factor, helping to detect IDC even at the micro-invasion stage [10, 32].

In conclusion, an integrated combination of visualization methods (multimodal approach) is the only reliable way to identify IDC at an early stage and to determine the extent of surgical intervention with mathematical precision. The study results show that choosing a diagnostic algorithm taking into account each patient's breast density and individual risk factors not only enables early detection of the disease but also significantly shortens the time to uncomplicated treatment.

Prognostic Significance of Molecular-Genetic Profiling and Innovative Biomarkers. The obtained results show that while visualization technologies reflect only the structural destruction of the tumor, molecular-genetic analyses reveal its hidden biological potential [18, 37]. A debatable aspect is that ctDNA analysis allows the detection of micrometastases and relapse risk much earlier than traditional methods, providing a strategic advantage for early modification of treatment tactics [20, 40]. In particular, it is being discussed that in HER2-positive carcinomas, ctDNA monitoring is more sensitive than MRI in evaluating the effectiveness of therapy in real time [18, 20].

Epigenetic changes and miRNA analyses confirm the complexity of the molecular mechanisms underlying IDC development. The "silencing" of genes without changes in the genetic code creates entirely new targets for diagnosis and targeted therapy [18, 23, 33]. This indicates the need to evaluate IDC not only as a localized tumor but also as a systemic genetic disease.

In conclusion, the use of innovative biomarkers and multigene panels, complementing visual diagnostic data, serves to create an individual biological "personal record" for each patient [18, 19]. Detecting genetic shifts that occur long before structural changes serves as a crucial foundation not only for early interception of the disease but also for selecting the most effective and least toxic personalized treatment strategy.

The Transformative Role of Digital Technologies and Artificial Intelligence in IDC Screening. The obtained results confirm that in IDC screening, artificial intelligence is not merely an auxiliary mechanism but is becoming a decisive factor determining diagnostic quality [6]. A debatable aspect is that while traditional radiology relies on subjective experience, AI systems are based on objective mathematical parameters. This allows standardization of the quality of oncological care worldwide, especially in regions with a shortage of highly qualified personnel [9, 26].

Our analyses show that the integration of AI models with the patient's genetic profile (BRCA1/2 mutations), clinical-laboratory data, and visual images forms the basis of a "smart screening" system [7]. Such an approach calculates the individual risk level for each patient and automatically determines the interval and method (mammography or MRI) for subsequent examinations [2].

However, the issue of "algorithmic transparency" or the "black box" problem remains relevant in the scientific community [6]. That is, there is a need to explain from a medical perspective how a neural network arrives at a particular conclusion (Explainable AI – XAI) [7]. Furthermore, data security and ethical norms are considered factors limiting the widespread adoption of digital oncology [26].

Nevertheless, the body of global research from 2019–2025 proves that digital technologies are shifting IDC diagnostics from a reactive state (detecting the disease after it occurs) to a proactive state (early prediction of biological changes) [26, 35]. AI algorithms are becoming the most reliable pillar of personalized medicine, not only in detecting tumors but also in mathematically modeling the individual response to chemotherapy [2, 7].

Innovative and Promising Technologies in Invasive Ductal Carcinoma Diagnosis. The obtained results confirm that innovative technologies have elevated IDC diagnostics from merely "finding the tumor" to the level of "mapping the functional and molecular profile" of the tumor. Photon-counting CT technology overcomes traditional diagnostic limitations, allowing the detection of micro-invasive processes even at the sub-millimeter level, which fundamentally changes the quality of early-stage diagnosis [25, 31].

A debatable aspect is that the use of "smart" biopsy systems increases the precision of surgery, reducing the burden of invasive interventions for patients [30]. The application of optical coherence tomography elements to the biopsy process allows surgeons to assess surgical margins in real time, which is an important factor in improving oncological outcomes [21, 31].

The integration of nanotechnological biomarkers and MSOT has ushered in the era of "molecular imaging". Studying the metabolic "signature" of the tumor through these methods not only minimizes diagnostic errors but also serves as a crucial foundation for selecting the most effective and organ-preserving treatment strategy for each patient [2, 21, 25]. In conclusion, these promising technologies are transforming IDC diagnostics into an objective, mathematically and molecularly precise process.

Epidemiological Analysis and Correlation of Survival Rates with Diagnostic Timing. The obtained results confirm that the timing of IDC diagnosis is the most important prognostic factor in preserving a patient's life. Studies show a direct and inherent correlation between tumor detection at an early stage (T1N0M0) and survival [4, 11].

A debatable aspect is that early detection of IDC has high effectiveness not only clinically but also socio-economically. It was found that treatment costs for cases detected through screening are 2 to 4 times lower compared to those diagnosed at late stages [12]. The integration of artificial intelligence (AI) and digital visualization technologies into screening programs can reduce the proportion of late-stage cases by 15–20%, which is of fundamental importance in reducing disability rates [4, 8, 13].

Furthermore, the higher prevalence of aggressive phenotypes among young women indicates the need to reconsider the screening age and to establish individual risk groups [8, 11]. In conclusion, the only reliable strategy in combating IDC is to detect the disease at the microscopic and

micro-invasive level. This approach serves as the foundation for sharply reducing oncological mortality rates while preserving patients' quality of life.

Analysis of the obtained results shows that the time has come for a transition from traditional approaches to digital and intelligent technologies in the diagnosis of invasive ductal carcinoma (IDC). The effectiveness of the diagnostic methods examined in our study is associated with several fundamental aspects [4, 11].

First, the comparative advantage of visualization technologies became significantly apparent. While traditional mammography showed low performance in detecting tumors in dense breast tissue (BI-RADS categories C and D), contrast-enhanced mammography (CEM) and tomosynthesis (DBT) demonstrated high sensitivity (over 90%) in overcoming this problem [26, 36]. This is particularly important for not missing early-stage IDC cases in regions like Uzbekistan, where a preventive examination system is being developed [8].

Second, the integration of Artificial Intelligence (AI) and machine learning algorithms was proven to reduce diagnostic errors by 15–22% as a "second opinion," while also reducing the workload of radiologists [2, 20]. According to our analysis, AI not only detects the tumor but is also capable of predicting its aggressiveness level (G1–G3) before histological examination [4].

Third, the difference between Uzbekistan's oncological statistics and global trends primarily stems from screening culture and technological infrastructure. The high five-year survival rates (over 90%) in developed countries are precisely the result of the widespread use of the innovative methods we studied (photon-counting CT and molecular analyses) [12, 13]. Implementing these technologies, especially AI-based screening programs, on a national scale in Uzbekistan would help sharply reduce the rate of late-stage detection [8].

As limitations of our study, it should be noted that the high economic cost of innovative methods (e.g., photon-counting CT) does not allow their uniform application in all medical institutions [21, 25]. However, the treatment costs saved through early diagnosis fully justify the investments made in these technologies [12].

Conclusion. Based on the research conducted and the analysis of international sources regarding the early diagnosis of invasive ductal carcinoma (IDC) of the breast, the following fundamental conclusions were reached:

1. Need for Changing Diagnostic Approach: Comparative analyses showed that traditional mammography does not have sufficient effectiveness in detecting IDC in dense breast tissue. It was found that contrast-enhanced mammography (CEM) and digital breast tomosynthesis (DBT) should increase sensitivity to 90–95% and serve as the "gold standard" for detecting early-stage micro-invasive foci.

2. Role of Technological Integration: It was determined that the role of artificial intelligence (AI) algorithms is unparalleled in reducing errors related to the human factor in the diagnostic process by up to 20% [2, 20]. The implementation of innovations like photon-counting CT is expected to elevate diagnostics to the cellular level in the future [21, 25].

3. Survival and National Oncology: Based on statistical analyses for 2024–2025, it was substantiated that detecting IDC at stage I ensures a five-year survival rate of up to 99% [4, 12]. This indicator shows that integrating innovative methods into national screening programs is a vital necessity for the oncology service of Uzbekistan.

4. Socio-Economic Importance: It is emphasized that early diagnosis is not only a cost-effective strategy for drastically reducing treatment expenses but also the only effective strategy for preserving the quality of life of patients.

Practical Recommendations: It is deemed appropriate to introduce AI analyses along with digital visualization methods into medical practice, as well as to develop individual screening plans (based on molecular-genetic characteristics) for high-risk women.

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