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Revolutionizing Cancer Care: The Role of Artificial Intelligence in Diagnosis, Prognosis, and Personalized Medicine

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Abstract: *cancer remains a leading cause of morbidity and mortality worldwide, with nearly 20 million new cases and 9.7 million deaths reported in 2022. The increasing burden of cancer, driven by population growth and aging, necessitates innovative solutions to improve diagnosis, prognosis, and treatment outcomes. Artificial Intelligence has emerged as a transformative tool in oncology, offering significant potential in cancer detection, diagnosis, and personalized treatment strategies. This review explores the real-world applications of Artificial Intelligence in oncology, focusing on lung cancer and Место для уравнения.breast cancer, two of the most prevalent and deadly cancers globally. Artificial Intelligence-driven technologies, particularly in imaging, pathology, and genomics, have demonstrated remarkable success in enhancing early detection, diagnostic accuracy, and treatment planning. In lung cancer, Artificial Intelligence-powered imaging tools, such as deep learning models, have shown high sensitivity and specificity in detecting small pulmonary nodules, often missed by traditional methods. Similarly, in breast cancer, Artificial Intelligence has proven effective in mammography interpretation, reducing false positives and false negatives, and alleviating the workload of radiologists. Despite its promising potential, the integration of Artificial Intelligence into clinical practice faces several challenges, including issues related to data quality, algorithmic biases, and ethical considerations. The "black box" nature of many Artificial Intelligence systems poses a significant barrier to clinical acceptance, highlighting the need for explainable Artificial Intelligence to provide transparent and interpretable decision-making processes. Furthermore, the successful implementation of Artificial Intelligence in oncology requires robust regulatory frameworks and standardized protocols to ensure patient safety and data security. This review underscores the transformative potential of Artificial Intelligence in revolutionizing cancer care, emphasizing the importance of addressing key challenges to harness its full potential. By enhancing early detection, reducing diagnostic errors, and enabling personalized treatment strategies, Artificial Intelligence has the potential to significantly improve patient outcomes and reduce the global burden of cancer. However, its successful integration into clinical practice will depend on interdisciplinary collaboration, ethical considerations, and a commitment to responsible implementation.*

Keywords: Artificial Intelligence; Biomarkers; Breast Neoplasms; Lung Neoplasms; Pathology.

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Introduction

Cancer remains one of the leading causes of morbidity and mortality worldwide, with nearly 20 million new cases and 9.7 million cancer-related deaths reported in 2022. Current estimates suggest that 1 in 5 individuals will develop cancer during their lifetime, with approximately 1 in 9 men and 1 in 12 women succumbing to the disease. By 2050, over 35 million new cases are projected annually, representing a 77% increase compared to 2022, driven by population growth and aging trends [1].

The high cost of cancer treatments poses financial challenges for patients and healthcare systems, affecting treatment decisions and access even today [2]. Moreover, oncology faces numerous challenges that necessitate innovative solutions to improve cancer treatment and patient outcomes. Key challenges include drug resistance, the need for personalized medicine, and the integration of digital health technologies [3].

Artificial Intelligence (AI) is being utilized across multiple domains in oncology, including radiology, pathology, genomics, and clinical decision support [4]. It aids in cancer detection, diagnosis, and treatment by analyzing complex datasets such as imaging, genomics, and medical records [5]. Machine learning (ML) and deep learning (DL) techniques are particularly effective in mining data for tumor screening, diagnosis, and prognosis, thereby supporting precision medicine [6]. Recent achievements in precision medicine include the analysis of multi-omics data, which encompasses genomics, transcriptomics, and proteomics. This enables the development of targeted treatment strategies tailored to individual patients, improving clinical outcomes. Additionally, the ability to identify new biomarkers further supports personalized treatment plans [7]. Despite its promising potential, AI in oncology faces several challenges. These include issues related to data quality, algorithmic biases, and the need for ethical and responsible AI design. The integration of AI into clinical practice is also hindered by regulatory oversight and the need for validation in oncology-specific settings [8].

AI, as a term, refers to a branch of computer science that emulates human intelligence. These systems are developed and programmed to perform cognitive functions such as decision-making, problem-solving, and learning [9]. ML is a subfield of AI, defined as a computational system based on a set of algorithms for analyzing data. It uses multiple layers of analysis to "learn" from initial data and "predict" future outcomes [10]. With each instance of data processing, the expansion of the dataset, adjustments in the arrangement of layers, and the depth of analysis, the quality of classification, regression, and data clustering significantly improves for specific tasks [11]. DL is an ML technique that comprises multiple layers of convolutional neural networks (CNN) [12]. DL incorporates different functional layers of artificial neurons or "nodes," such as input layers, multiple hidden layers, and output layers [9]. Each "node" is connected to the initial and deeper layers via edges, and the strength of their connection is referred to as "weight" [13]. The input layer typically contains quantified values derived from the dataset of interest. For example, in AI-assisted histopathology image analysis, this data could represent the intensity value of a specific pixel in an image. The deeper, hidden layers of the DL model perform feature construction, refining the representations from previous layers [14]. Such algorithms can "learn" feature representations automatically, avoiding bias and unnecessary additional engineering, and providing accurate end-to-end results [15]. For instance, the differences between ML and DL algorithms for implementation in histopathology include training style, training time, algorithm complexity, data size, and data processing resources. While ML algorithms can train faster and have less complex structures, they are typically trainable with smaller datasets and require fully annotated data. In contrast, DL algorithms require significantly more training time, have highly complex models, and can produce accurate results with very large datasets and diverse levels of data annotation [16].

Aim

This study aims to analyze real-world applications of AI in oncology, focusing on its role in cancer diagnosis, prognosis, and treatment. By reviewing successful case studies and current AI-driven projects, this research

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seeks to identify the best practices for integrating AI into clinical workflows in lung cancer (LC) and breast cancer (BC).

Materials and Methods

This review examined scientific works related to the application of AI models in oncology, focusing on publications from 2020 to 2024 available in scientific databases. The analysis of medical articles we conducted using combinations of the following terms: artificial intelligence, deep learning, machine learning, lung neoplasms, and breast neoplasms. More than 1,100 articles were reviewed to assess their originality and to ensure a diverse representation of the wide range of applications of AI systems in oncology-related contexts and 56 sources for references were selected that are most relevant to the topic. We chose LC and BC as the materials for our study, since these two malignant tumors were the most frequently encountered when processing the data. When analyzing the literature, we also paid attention to the use of the statistical AUC (area under the curve) metric of binary classification quality to evaluate the effectiveness of the AI model by the authors and considered only those articles where the AUC is more than 0.7.

Review and Discussion

The global AI in oncology market was valued at USD 2.80 billion in 2023 and is expected to grow at a compound annual growth rate of 28.92% from 2024 to 2030 [17], thus the medical community suggests that trends in financial growth, combined with the projected increase in the morbidity and prevalence of oncology-related conditions [1], makes a significant potential for the rapid implementation of AI-related technologies in clinical practice. This could also lead to the establishment of reliable "pipelines," laws, and standards for trustworthy and effective oncology treatment in the coming years.

Considering the current statistics of cancer incidence, LC remains one of the most prevalent and deadly cancers worldwide, with over 1.9 million cases reported globally in 2022 and more than half a million deaths attributed to it [18]. Traditionally, LC diagnosis relies on imaging techniques such as computed tomography (CT) and positron emission tomography (PET), which are considered the gold standard for identifying abnormal masses or tumors in the lungs [18]. However, accuracy of these methods is relatively low for early-stage LC detection and can be affected by various factors such as lung vacuolation or tissue reshaping [19] and AI-powered imaging tools, such as DL models, show great promise in improving early detection precision. These tools can identify small pulmonary nodules with high sensitivity and specificity, even for nodules as small as 3-5 millimeters and they can also flag suspicious areas for further review, which might easily be overlooked by the human eye [20].

For instance, a study by Liu et al. demonstrated that AI-assisted CT imaging achieved a sensitivity and specificity of 87%, with an AUC of 0.93. Their findings suggest that AI-assisted diagnostic systems for CT imaging exhibit high diagnostic accuracy for LC detection and hold significant potential for improving early detection rates. No less important, in our opinion, the study also highlights the limitations of human-driven diagnostic methods, which rely on manual pathology section analysis and the subjective nature of film reading, potentially leading to misdiagnoses [21]. However, it is important to note that AI-driven methods are significantly constrained by untimely data updates and small sample sizes, which can reduce their potential benefits and delay full development. A study by Kiraly et al. evaluated the importance of AI in LC screening across cohorts in the USA and Japan, involving 627 low-dose CT cases, where 141 cancer-positive cases were interpreted by 12 radiologists. The use of AI systems improved specificity by 5.5% in the USA and 6.7% in Japan, with no significant loss in sensitivity [22]. This work highlights the advantages of AI-assisted imaging in avoiding unnecessary lung biopsies, reducing overaggressive follow-up imaging.

From a pathomorphological point of view LC is a heterogeneous disease with various subtypes that behave differently, small-cell LC, may be especially difficult to detect early or may grow slowly, making them challenging to identify in the initial stages [23]. Avanzo et al. demonstrated the great capabilities of AI in early differentiation of LC by applying support vector

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machine to distinguish adenocarcinoma from focal pneumonia based on CT and PET scans, achieving an accuracy of 87.6%. Additionally, their study highlighted AI's strength in assessing radiation effects and immunotherapy-induced pneumonitis, alongside its ability to differentiate between adenocarcinoma and pneumonia, and underscores AI's future influence to clinical practice in precise classification and early detection [24].

According to many authors, in addition to imaging for detecting malignant lung lesions, tumor markers (e.g., TTF-1, Napsin A, Rb, ALK, EGFR) are crucial for credible cancer identification, however, the clinical use of many well-known and newly identified biomarkers remains limited due to inconsistencies in oncology diagnosis and prognosis [25, 26]. A retrospective study by Zheng et al. utilized radiomics and ML to predict recurrence and survival outcomes in patients with LC. Using data from 217 patients, the study achieved an AUC of 0.79 in the training cohort and 0.70 in the validation cohort for prediction of lymph node metastasis in stage I-IIIB non-small cell LC [27]. The next important diagnostic criterion in LC diagnosis is nodule segmentation relies on image analysis that outlines lung nodule boundaries from the surrounding thoracic structures. This allows for the accurate measurement of nodule volume and size, as well as the determination of nodule composition and potential malignancy [28]. The research of Aydin et al. highlighted the strong AI's capability in predicting invasive adenocarcinoma from pure ground-glass nodules using CNN. Their study included 301 patients with LC pathologies, achieving a sensitivity of 0.93, a precision of 0.82, and an F1 score of 0.87 in detecting LC [29]. The methods demonstrated in these studies have the potential to enhance personalized treatment planning by noninvasively and accurately identifying high-risk patients, thereby improving preoperative staging and guiding adjuvant therapies.

Precise diagnosis in LC often relies on histological examinations, such as percutaneous puncture biopsy or bronchoscopy. These methods place a significant workload on oncology specialists. Rączkowska et al. showcased a CNN-based approach for tumor microenvironment segmentation. Their study generated 23,199 image patches from hematoxylin-and-eosin-stained LC tissue. The CNN model achieved an AUC of up to 0.99 for tissue type classification in LC, a c-index of 0.723 for survival prediction, and an AUC of up to 73.5% for mutation classification [31]. This study not only demonstrated the strong trainability of AI for tissue classification in histopathology diagnosis of LC but also provided important insights for designing novel cancer treatments. Their work suggests the potential for AI to expand our understanding of the tumor microenvironment's effect on the tumor evolutionary process, and also AI can accurately assist in tumor grading, identifying molecular markers, and predicting treatment responses [30].

Another study related to histopathology detection of LC was presented by Noaman et al., which utilized various AI-related solutions, such as ML support vector machine, decision trees, random forests, and multinomial naïve Bayes, along with color histogram techniques for histopathological classification. Their approach achieved a remarkable accuracy of 99.683% for LC detection. When extended to BC detection, the same method achieved a commendable accuracy rate of 94.808% [32]. In our opinion, Noaman et al.'s study demonstrated the notable stability and universality of AI models, which allows for the successful reuse of the technology across different oncology areas without requiring excessive updates.

Another leading cause of cancer worldwide, according to US statistics for 2024, is BC in women: 310,720 new invasive cases, 56,500 cases of ductal carcinoma in situ, and 42,250 deaths per year [33]. The most common factors that increase the risk of BC development include family history, environmental exposures, mutations in the BRCA1 and BRCA2 genes, long-term exposure to estrogen, and late menopause [34, 35]. Given the dire projections for the rise in BC incidence and the complexity of risk factor combinations, we believe AI has the potential to be a transformative tool in clinical oncology in terms of accurate diagnosis, workload optimization, and facilitating perso-

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nalized treatment planning, ultimately leading to improved patient outcomes [36, 37]. Unfortunately, AI currently lacks the necessary quality and quantity of data for widespread implementation in real-world clinical practice, but the accuracy and specificity demonstrated in relatively small studies offer great promise for the future of AI in BC screening [38].

Interpreting mammograms is a complex and time-consuming task, and breast abnormalities can be missed by human radiologists. Using AI systems to identify structural abnormalities can significantly reduce false-positive and false-negative results, allowing for earlier detection and more accurate diagnosis. For example, Lotter et al. applied a DL model to mammography, which outperformed five specialists, increasing sensitivity by 14% in classifying the mammograms. This method was able to detect cancer at low screening rates and identify cancer in clinically negative previous mammograms [39,40].

Additionally, early detection of BC is critical to improving survival rates, increasing the chances of remission and improving overall patient outcomes [41]. This was demonstrated by the authors McKinney et al. who developed an AI system capable of outperforming human experts in interpreting mammograms, demonstrating its ability to more accurately and effectively assist in the early detection of BC. Their study showed an absolute reduction in false positives of 5.7% (US) and 1.2% (UK), and false negatives of 9.4% (US) and 2.7% (UK) [42].

Equally important in the clinical use of AI for BC screening is overcoming the limitations of human interpretation of mammography. A solution to this problem was solved by Schaffter et al., who combined the most effective AI algorithms, and their study achieved an AUC of 0.942 and 92.0% specificity with the same sensitivity [43]. While no AI algorithm has outperformed a doctor's trained eye, the combination of AI and a radiologist has significantly improved the accuracy of screening by a single user.

Naturally, the undeniable advantage is the ability of AI to ease the burden on healthcare professionals by automating repetitive and time-consuming tasks such as image interpretation, pathology assessment, and administrative documentation. AI-powered systems can generate preliminary reports, prioritize urgent cases, and reduce diagnostic errors, allowing oncologists and radiologists to focus more on complex decision-making and direct patient care [44]. In a study by Ng et al., AI was evaluated as a secondary reader in a multi-site study and the results showed that AI-assisted reading reduced the need for a second human review by 87% while maintaining screening quality, and when used as an independent reader, AI reduced the number of cases referred to arbitration from 13% to 2% [42,45,46]. It appears that soon, if implemented in widespread medical practice, AI could improve overall efficiency, enhance interdisciplinary collaboration, and reduce burnout among healthcare workers. A retrospective cohort study by Rai-Povedano et al. analyzed data from the Cordoba Tomosynthesis Screening Trial, which included 15,986 women screened using AI-enhanced digital mammography and showed a 72.5% reduction in workload compared to traditional dual reading.[47]. A study by Pacilè et al. examined the impact of AI-assisted mammography on improving radiologists' diagnostic accuracy and examination time, with a diagnostic accuracy of AUC 0.797 and reading time of 62.79 seconds per case.[48]. We found interesting a population-based study by Lang et al. that demonstrated that AI can also classify mammograms into low- and high-risk categories, reducing unnecessary readings and minimizing false positives [49]. The results of these studies are promising and confirm the ability of AI to improve the efficiency of population screening, although further retrospective studies are needed.

The integration of AI into oncology faces certain complexities and critical issues that go beyond technical advances and touch upon fundamental ethical, regulatory, and clinical concerns. A major hurdle is the robustness and generalizability of AI models. Many algorithms are trained on datasets that may not be representative of diverse patient populations, introducing bias that can lead to suboptimal treatment recommendations for underrepresented groups [50]. The very promise of accurate

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diagnostics that AI aims to realize risks being undermined by inconsistencies in data quality, as well as differences in access to advanced AI tools across healthcare settings [51]. Without standardized, high-quality data, many experts say AI risks perpetuating rather than reducing inequalities in cancer care [52].

Beyond the technical aspects, the role of AI in clinical decision making raises ethical and professional concerns [53]. Oncologists should be solely responsible for patient care, but the growing presence of AI in diagnostic imaging, treatment recommendations, and predictive analytics is blurring the lines of responsibility [54]. The lack of transparent decision-making processes in many AI systems, often described as "black boxes," creates problems among physicians who may find it difficult to interpret the information generated by AI [55]. This is where the need for explainable AI becomes critical. Explainable AI ensures that the rationale behind an AI model's recommendations is clear, interpretable, and clinically sound. Rather than simply providing an output, explainable AI allows oncologists to understand why a particular decision was made, facilitating informed decision-making and building trust in AI-powered oncology as a whole [56]. Without such interpretability, AI risks being seen as an opaque and unaccountable tool rather than a reliable support system in clinical practice.

Conclusions.

Our review of recent scientific research on the role of AI in oncology leads us to conclude that integrating AI into the diagnosis and treatment of LC and BC will drive a transformative shift in the medical field in the coming years. AI-driven technologies, particularly in imaging, pathology, and genomics, have shown significant potential in enhancing early detection, improving diagnostic accuracy, and advancing personalized treatment strategies. By leveraging ML and deep DL algorithms, AI can analyze complex datasets, such as medical imaging and multi-omics data, to identify subtle patterns that may be overlooked by human clinicians. This capability is especially crucial in the early stages of cancer, where timely intervention can significantly improve patient outcomes.

In LC, AI has shown remarkable success in enhancing the accuracy of imaging techniques like CT and PET scans, enabling the detection of small pulmonary nodules that are often missed by traditional methods. AI's ability to differentiate between benign and malignant lesions, as well as its potential to predict treatment responses, underscores its value in reducing unnecessary biopsies and optimizing treatment plans. Similarly, in BC, AI has proven to be a powerful tool in mammography interpretation, reducing false positives and false negatives, and alleviating the workload of radiologists. Studies have shown that AI-assisted systems can outperform human experts in certain cases, leading to earlier detection and more accurate diagnoses.

However, the widespread adoption of AI in oncology is not without challenges. Issues related to data quality, algorithm biases, and the need for ethical and responsible AI design must be addressed to ensure equitable and effective implementation. The "black box" nature of many AI systems poses a significant barrier to clinical acceptance, as oncologists require transparent and interpretable decision-making processes to trust and effectively utilize AI-generated insights. Explainable AI is therefore essential in bridging this gap, providing clinicians with clear and justifiable reasoning behind AI recommendations.

Moreover, the integration of AI into clinical workflows must be accompanied by robust regulatory frameworks and standardized protocols to ensure patient safety and data security. The potential for AI to exacerbate healthcare disparities, particularly in underrepresented populations, highlights the need for diverse and high-quality datasets in training AI models. As AI continues to evolve, interdisciplinary collaboration between oncologists, data scientists, and policymakers will be crucial in harnessing its full potential while addressing ethical and practical concerns. As we move forward, the continued development of AI technologies, coupled with a commitment to responsible implementation, will be essential in realizing the transformative potential of AI in oncology.

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Consent to publication

The work is of a review nature, and all rules and regulations of the Committee on Ethics of Scientific Publications (COPE) were observed during its preparation and writing.

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A – Research concept and design, B – Collection and/or assembly of data, C – Data analysis and interpretation, D – Writing the article, E – Critical revision of the article, F – Final approval of article

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Революція в лікуванні раку: роль штучного інтелекту в діагностиці, прогнозуванні та персоналізованій медицині

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Анотація: *рак залишається однією з провідних причин захворюваності та смертності у світі, причому у 2022 році було зареєстровано майже 20 мільйонів нових випадків і 9,7 мільйона смертей. Зростаюче навантаження, спричинене зростанням населення та його старінням, вимагає інноваційних рішень для покращення діагностики, прогнозування та результатів лікування. Штучний інтелект став революційним інструментом в онкології, що відкриває значний потенціал у виявленні раку, діагностиці та розробці персоналізованих стратегій лікування. Цей огляд розглядає реальні застосування штучного інтелекту в онкології, зосереджуючись на раку легень і раку молочної залози — двох із найпоширеніших і найсмертельніших видів раку у світі. Технології, що орієнтовані на штучний інтелект, зокрема у візуалізації, патології та геномиці, досягли значного успіху у вдосконаленні раннього виявлення, підвищенні точності діагностики та покращенні планування лікування. У випадку раку легень інструменти візуалізації на основі штучного інтелекту, зокрема глибокі нейронні мережі, продемонстрували високу чутливість і специфічність у виявленні дрібних легеневих вузлів, які часто залишаються непоміченими традиційними методами. Подібним чином, у діагностиці раку молочної залози штечний інтелект довів свою ефективність в інтерпретації мамографічних зображень, зменшуючи кількість хибнопозитивних і хибнонегативних результатів, а також зниження навантаження на радіологів. Незважаючи на перспективний потенціал, інтеграція штучного інтелекту в клінічну практику стикається з численними викликами, що включають питання якості даних, алгоритмічні упередження та етичні аспекти. «Чорний ящик» багатьох систем штучного інтелекту є серйозним бар'єром для їх прийняття в клінічній практиці, що підкреслює необхідність розробки пояснюваного штучного інтелекту для забезпечення прозорості та інтерпретованості прийняття рішень. Крім того, успішна імплементація штучного інтелекту в онкологію потребує створення надійних регуляторних рамок та стандартизованих протоколів для гарантування безпеки пацієнтів і захисту даних. Цей огляд висвітлює трансформаційний потенціал штучного інтелекту у революціонізації онкологічної допомоги, наголошуючи на важливості подолання ключових викликів для реалізації його повного потенціалу. Завдяки вдосконаленню раннього виявлення, зниженню діагностичних помилок і забезпеченню персоналізованих стратегій лікування штучний інтелект може суттєво покращити результати лікування пацієнтів і зменшити глобальне навантаження онкологічних захворювань. Проте його успішна інтеграція в клінічну практику буде залежати від міждисциплінарної співпраці, підходів згідно етичних протоколів і відповідального впровадження.*

Ключові слова: Біомаркери; Новоутворення легенів; Новоутворення молочної залози; Патологія; Штучний інтелект.