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Review Article

Artificial Intelligence in Oncology: Advancing Precision, Prediction, and Personalized Cancer Care

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ABSTRACT

Cancer's biological complexity, intra- and inter-tumoral heterogeneity, and variable patient responses to therapy make it a formidable challenge and one of the world's leading causes of morbidity and mortality. The development of artificial intelligence (AI) and its subfields, such as machine learning (ML) and deep learning (DL), has transformed oncology by making it possible to manage cancer in a precise, individualized, and data-driven manner. From early detection and diagnosis to treatment planning, drug discovery, and prognosis prediction, recent developments (2022–2025) have incorporated AI into every aspect of cancer care. Through the processing of multimodal datasets, including digital pathology, proteomics, transcriptomics, genomics, and radiomics, AI algorithms can find molecular signatures and hidden biomarkers that direct specialized therapeutic interventions. Furthermore, compared to conventional clinical evaluation techniques, AI-based models have demonstrated encouraging accuracy in tumor segmentation, histopathological classification, and survival prediction. By combining cloud-based AI platforms with big data analytics, clinical decision-making has improved and real-time monitoring of treatment response and side effects is now possible. Data bias, interpretability, model generalizability, and ethical considerations continue to be major obstacles to full clinical implementation, despite its transformative potential. This review summarizes the most recent advancements in AI-driven oncology, emphasizing technological advancements, practical uses, and potential avenues for further study. It highlights how AI is bringing about a new era in intelligent, evidence-based cancer care by advancing early diagnosis, tailored treatment, and better patient outcomes in precision medicine.

INTRODUCTION

The World Health Organization (WHO) estimates that 10 million people die from cancer each year, and that nearly 20 million new cases are

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diagnosed, making it one of the most serious global health issues. Even with major advancements in molecular biology, diagnostic imaging, and treatment, cancer is still very diverse in terms of both genetic makeup and phenotype. Patients with morphologically similar tumors frequently react differently to standard treatments because of underlying variations in lifestyle factors, immune microenvironment, protein expression, and genomic alterations. As a result, there is an increasing need for precision oncology, a method that customizes medical judgments and therapies to each patient's unique circumstances. In clinical oncology and biomedical research, artificial intelligence (AI) has become a game-changing technology in recent years. The term artificial intelligence (AI) describes computer programs that can simulate human cognitive processes like learning and reasoning. Throughout the whole cancer care spectrum, from early screening and risk assessment to diagnosis, treatment planning, prognosis prediction, and post-treatment surveillance, artificial intelligence is being used in oncology. In digital pathology, CT, MRI, and mammography, for instance, AI-powered image recognition models like convolutional neural networks (CNNs) have attained expert-level accuracy in identifying cancers. In a similar vein, machine learning algorithms have assisted in the creation of customized treatment plans, predicted drug resistance, and discovered new biomarkers. Approaches that improve model transparency, data security, and clinical usability—explainable AI (XAI), multi-omics integration, and federated learning—have drawn more attention in research between 2022 and 2025. In order to overcome major obstacles that currently prevent widespread clinical adoption, such as data heterogeneity, algorithmic bias, and ethical constraints, these advancements are essential. By combining computational.

MATERIALS AND METHODS

1. Literature Search Strategy

In order to find current and pertinent research on the use of artificial intelligence (AI) in oncology that was published between January 2022 and September 2025, a thorough literature search was conducted. A thorough search was conducted across major scientific databases, including PubMed, Scopus, Web of Science, ScienceDirect, and Google Scholar. The terms “Artificial Intelligence,” “Machine Learning,” “Deep Learning,” “Neural Networks,” “Radiomics,” “Digital Pathology,” “Oncology,” “Cancer Diagnosis,” “Prognosis,” “Therapeutic Prediction,” “Precision Medicine,” and “Clinical Decision Support” were used both singly and in combination. To hone the search, boolean operators (AND, OR) were used. Other resources include conference proceedings, systematic reviews, and preprints from arXiv (e.g. G. IEEE, MICCAI, and ASCO) were incorporated to guarantee the most recent data.

2. Inclusion and Exclusion Criteria

The following inclusion criteria were used to choose the studies: They had to be published in English between 2022 and 2025. Centered on the use of AI, ML, or DL in drug discovery, treatment response prediction, prognosis, or cancer detection and diagnosis. Made use of verified datasets (e.g. G. institutional datasets, TCGA, SEER, ICGC, or ImageNet). Reported quantifiable results, like clinical utility, AUC (Area Under the Curve), sensitivity, specificity, or accuracy. Among the exclusion criteria were studies that had nothing to do with oncology. Articles that lack adequate methodological information. Editorials, non-peer-reviewed commentary, or opinion pieces.

3. Data Extraction and Categorization



For each qualifying study, data was gathered concerning: The type of cancer investigated (e.g., breast, lung, colorectal, brain, prostate). The AI model or algorithm employed (e.g., Random Forest, Support Vector Machine, Convolutional Neural Network, Transformer models). The type of dataset used (radiomics, genomics, histopathology, clinical data, etc.). The performance metrics and the clinical application. The limitations and suggestions for future research highlighted by the authors.

The gathered information was categorized into thematic sections to aid in synthesis:

1. AI in cancer detection and screening
2. AI in tumor characterization and staging
3. AI in treatment planning and drug development
4. AI in prognosis and survival prediction
5. AI in clinical decision support systems

4. Methodological Approach

This review utilizes an integrative perspective, combining quantitative and qualitative findings from various fields of oncology and computer science. The studies were assessed for their algorithmic strength, diversity of datasets, interpretability, and relevance to clinical practice. When possible, performance indicators (such as sensitivity, specificity, precision, recall, F1-score, ROC-AUC) were compared among similar cancer types or diagnostic methods. To maintain methodological integrity, the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines were adhered to for the selection and reporting of literature. A flowchart (not included here) illustrates the process of screening and selection.

5. Ethical and Data Considerations

In light of the incorporation of AI into clinical oncology, specific emphasis was placed on research exploring: Adherence to ethical standards (including patient consent and data anonymization). Strategies for minimizing bias in AI training datasets. The clarity of models and the frameworks for regulatory approval (such as those from the FDA and EMA). These elements were utilized to evaluate the potential for translating AI technologies from research environments into clinical settings.

Applications of Artificial Intelligence in Oncology

AI technologies have transformed the field of oncology by allowing for clinical decision-making that is grounded in data, evidence, and personalization. As medical data — such as imaging, molecular information, and clinical records — continues to grow rapidly, AI supports early diagnosis, accurate assessment, customized treatments, and predictions of outcomes. The following are the key areas where AI has significantly impacted.

1) Early Detection and Cancer Screening

The early identification of cancer is fundamental for effective management and control of the disease. AI algorithms, particularly deep learning models like convolutional neural networks (CNNs), can recognize subtle and intricate patterns in radiological and pathological images that may go unnoticed by human eyes.

I. In Radiology:

AI-enhanced imaging technologies have shown expert-level precision in screening for cancers such as breast (via mammography), lung (using CT scans), and prostate (through MRI). For



instance, AI-driven mammography systems have demonstrated sensitivity that is on par with or surpasses that of radiologists when detecting microcalcifications and early-stage lesions, thereby decreasing the likelihood of false negatives.

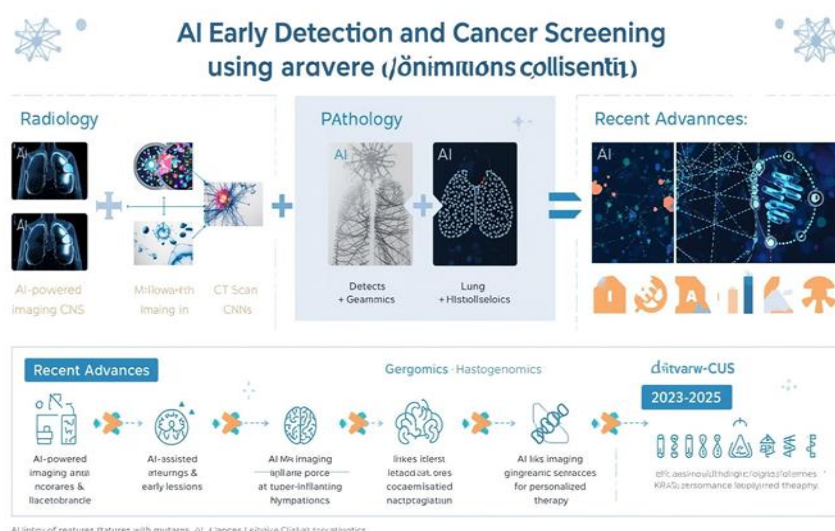
II. In Pathology:

In the realm of digital histopathology, AI is valuable for spotting unusual cell shapes and measuring tumor-infiltrating lymphocytes, which

are essential for early diagnosis. Additionally, the coupling of AI with liquid biopsy and the detection of circulating tumor DNA (ctDNA) holds promise for non-invasive, early cancer screening.

Recent Developments (2023–2025):

Hybrid approaches that integrate radiomics and genomics (radio genomics) have been utilized to link imaging characteristics with genetic alterations (such as EGFR and KRAS), enhancing early risk assessment.



2) Cancer Diagnosis and Classification

AI enhances the accuracy of diagnostics by examining intricate datasets, which include whole-slide histopathological images, next-generation sequencing (NGS) data, and imaging from radiological scans.

i. Deep Learning in Digital Pathology:

Systems based on convolutional neural networks (CNNs) can effectively differentiate tumor subtypes (such as adenocarcinoma versus squamous cell carcinoma) and assess the severity of malignancies with high precision. For instance, models like Vision Transformers (ViTs) and

Efficient Nets (2024) surpass previous architectures in tasks related to histopathological classification.

ii. Molecular and Genomic Diagnosis:

Machine learning algorithms evaluate genomic and transcriptomic information to detect driver mutations and categorize molecular subtypes. AI innovations, including Deep Variant and AlphaFold2, have transformed the interpretation of genomes and the prediction of protein structures, facilitating the identification of new cancer pathways.

iii. Impact:



AI diminishes diagnostic inconsistencies, aids pathologists in managing their workload, and improves the consistency of clinical interpretations.

3) Treatment Planning and Precision Therapy

One of the most significant uses of AI in cancer treatment is customizing therapy plans. AI combines patient information (such as genomics, tumor environment, medication sensitivity, and past treatment responses) to suggest the best therapeutic strategies.

Radiation Therapy Planning: AI systems help automate the identification of target areas, optimize dosage, and forecast potential radiation-related side effects. Advanced reinforcement learning techniques are being created to modify radiation dosages in real-time based on the tumor's response.

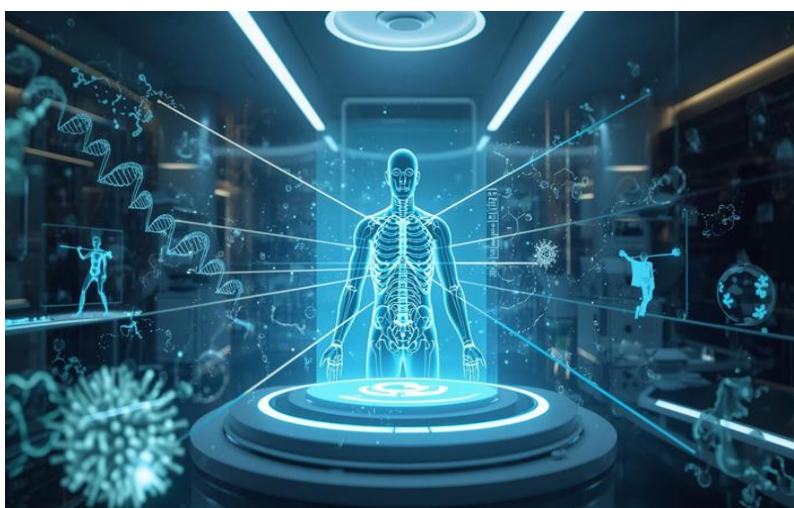
Chemotherapy and Targeted Treatment:

Machine learning algorithms can foresee drug resistance and interactions between drugs, enhancing the selection of treatments. AI-enhanced virtual drug screening and innovative drug development have sped up the identification of novel anticancer agents.

Immunotherapy:

AI models that predict outcomes assess patient immunogenomic data to determine which individuals are likely to benefit from immune checkpoint inhibitors (ICIs).

The integration of multi-omics has revealed biomarkers associated with PD-L1 expression, tumor mutational burden (TMB), and the presentation of neoantigens.



4) Prognosis and Survival Prediction

AI facilitates the forecasting of disease advancement, recurrence, and patient longevity by examining extensive longitudinal datasets.

Prognostic Analytics:

Machine learning models like Random Forests, Gradient Boosting Machines, and Survival Neural Networks assess clinical and molecular features to project overall survival (OS) and progression-free survival (PFS).

Radiomics-based Predictions:

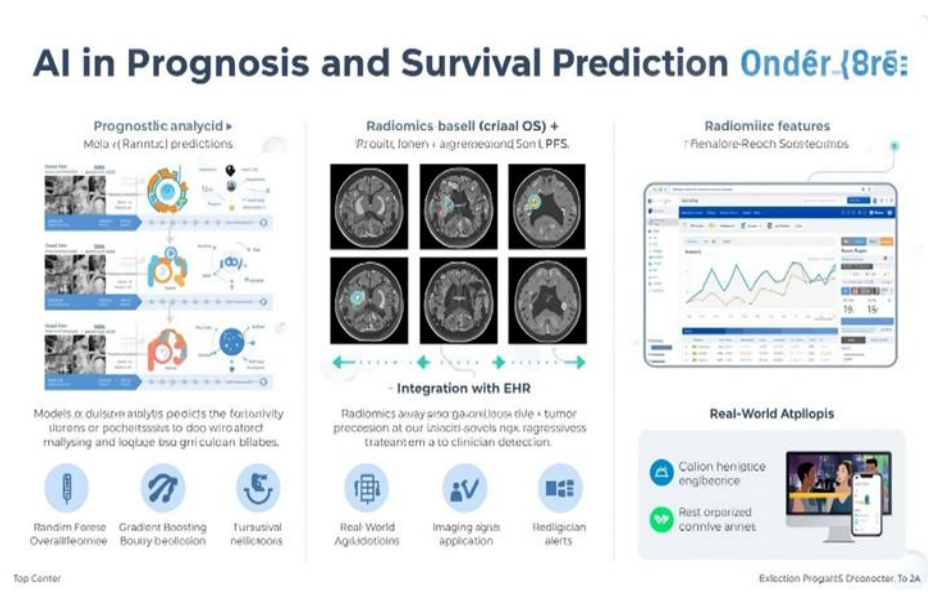
Quantitative imaging biomarkers obtained from CT/MRI scans aid in forecasting tumor aggressiveness and treatment results.

Integration with HER:

The application of predictive analytics to Electronic Health Records (EHRs) offers timely risk assessment and clinical notifications for potential relapses or complications.

Instances:

AI models utilized in breast and lung cancer are capable of predicting 5-year survival rates with over 85% accuracy. Multi-omics AI solutions merge genomic, proteomic, and metabolomic information for continuous patient monitoring.



5) AI in Clinical Decision Support Systems (CDSS)

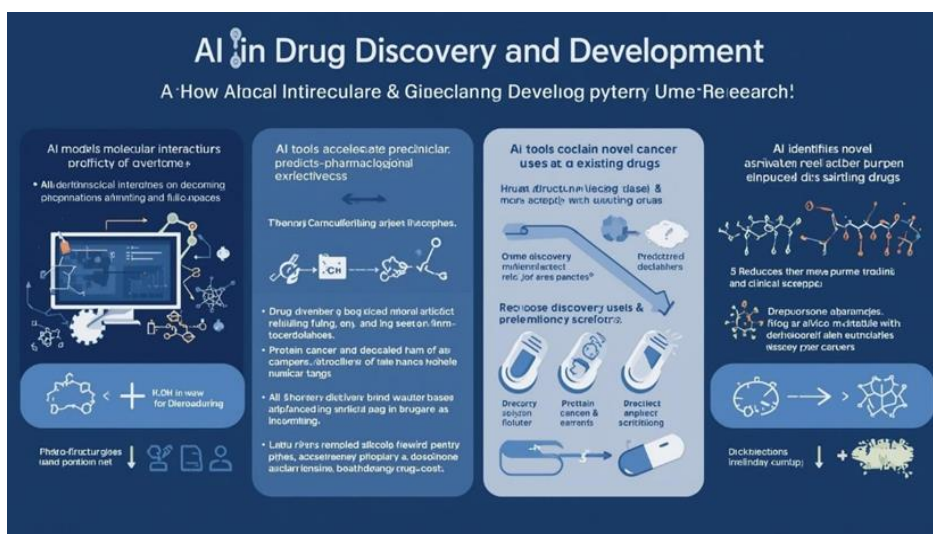
AI-enhanced Clinical Decision Support Systems connect computational insights with practical clinical application. These systems consolidate imaging, genomic, and clinical information into comprehensive dashboards for oncologists. AI supports tumor board discussions by recommending evidence-backed treatment options and predicting probable outcomes. Natural Language Processing (NLP) is utilized to extract important information from clinical notes, reports, and literature to aid in decision-making.

Recent Developments:

Generative AI models (such as GPT-based clinical assistants) are being created to summarize patient histories, propose diagnostic tests, and recommend treatment protocols, always under the supervision of a physician.

6) Drug Discovery and Development

The use of AI has expedited the process of drug discovery by modeling molecular interactions and forecasting pharmacological effectiveness. Deep learning algorithms estimate binding affinities, enhance drug-likeness, and identify new cancer-related uses for established medications. Technologies such as AlphaFold2 and DeepChem have notably reduced the duration of preclinical drug design.



7) AI in Cancer Research and Clinical Trials

AI enables:

Categorizing patients for clinical trials by utilizing molecular and phenotypic information. Automated surveillance of data for the identification of adverse events. Forecasting recruitment tools that streamline and accelerate clinical trials.



RESULTS AND DISCUSSION:

Impact of Artificial Intelligence in Oncology

A. Transformation of Cancer Diagnosis and Early Detection

AI has introduced a significant shift in how cancer is diagnosed, especially in the areas of imaging

and pathology. Various studies conducted between 2022 and 2025 indicate that AI-driven diagnostic systems now possess accuracy levels that are comparable to, and in some cases surpass, those of expert clinicians.

Radiological Imaging:



Models based on convolutional neural networks (CNN) have attained AUC values greater than 0.95 in identifying lung nodules, breast tumors, and colorectal lesions through CT, MRI, and PET scans. For example, the breast cancer detection model developed by Google DeepMind (Nature, 2023) decreased false positives by 5.7% and false negatives by 9.4%, greatly enhancing the efficiency of screenings.

Pathology:

The use of whole-slide imaging (WSI) in combination with AI has facilitated accurate histological grading, cell segmentation, and tumor subtyping, assisting pathologists in conducting high-volume diagnoses. New AI tools such as PaLM-Med2 (2024) are capable of recognizing rare cancer subtypes in histopathological images with over 90% classification accuracy.

Impact:

Programs that utilize AI for screening reduce the time it takes for diagnoses, decrease expenses, and enhance accessibility in underprivileged areas by automating standard image analysis duties.

B. Prognosis, Survival Prediction, and Disease Monitoring

AI is crucial for forecasting survival rates, recurrence probabilities, and long-term treatment results.

Survival Models:

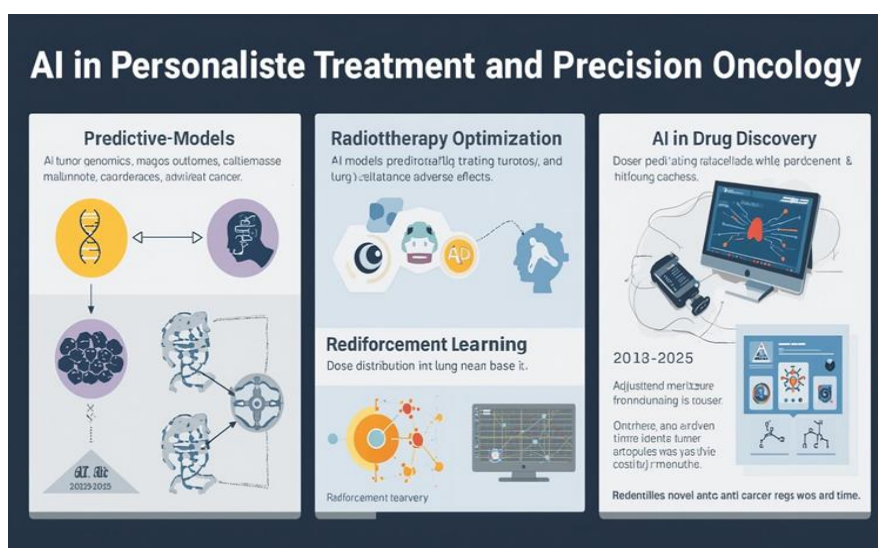
Survival neural networks (like DeepSurv and Cox-Time models) merge clinical and genomic information to estimate 5-year overall survival (OS) and progression-free survival (PFS) across various types of cancer. Recent multicenter studies (Nature Medicine, 2023) have shown that AI-driven prognostic models exceed traditional Cox regression in prediction accuracy by as much as 25%.

Dynamic Monitoring:

The combination of real-time electronic health record (HER) data with wearable biosensors facilitates ongoing disease monitoring and timely identification of relapse indicators.

Impact:

The early detection of relapses and predictive monitoring enable healthcare providers to act sooner, enhancing both life expectancy and quality of life.



C. Clinical Decision Support and Workflow Efficiency

AI-enhanced Clinical Decision Support Systems (CDSS) are increasingly being utilized in healthcare facilities to aid oncologists in making choices founded on evidence.

Integration into Clinical Workflows:

AI systems summarize diagnostic results, emphasize significant patterns, and propose tailored treatment options. Natural Language Processing (NLP) technologies pull essential data from clinical documentation and research, allowing oncologists to remain informed. Examples of AI-driven decision-making tools deployed worldwide include IBM Watson for Oncology and Onco Assist.

Effects:

AI alleviates the workload for clinicians, reduces delays in diagnosis, and enhances collaborative decision-making among tumor boards.

D. AI in Cancer Research and Clinical Trials

AI plays a role in the design, oversight, and evaluation of cancer clinical trials:

Patient Recruitment:

Predictive models identify patients who qualify for relevant trials based on their genomic and phenotypic characteristics.

Data Assessment:

Automated detection of anomalies provides real-time quality assurance for trial data.

Outcome Forecasting:

AI-driven models estimate trial results, supporting adaptive trial frameworks and lowering costs and timeframes.

Impact:

AI improves trial efficiency, encourages diversity in participant enrollment, and speeds up regulatory approvals for groundbreaking therapies.

E. Socioeconomic and Global Health Impact

Technologies in oncology powered by AI are closing the disparities in low- and middle-income countries (LMICs) by offering affordable diagnostic and decision-support solutions. AI-driven cloud platforms facilitate remote

diagnostics and virtual consultations. Portable AI imaging technologies, such as AI mammography and AI cytology kits, enhance cancer screening accessibility in settings with limited resources.

Impact:

AI fosters global health equity by lessening the gaps in cancer care provision.

F. Ethical, Legal, and Regulatory Challenges

Despite its immense possibilities, the incorporation of AI in oncology encounters significant obstacles:

Data Confidentiality and Safety: Maintaining adherence to HIPAA and GDPR standards is essential.

Equity and Bias: Models developed on biased information may lead to unequal results among different groups.

Understanding: The opaque nature of deep learning systems can hinder the trust of clinicians.

Regulatory Clearance: Only a handful of AI applications have received full approval from the FDA or EMA due to issues regarding consistency and reliability. Current initiatives like Explainable AI (XAI) and Federated Learning (FL) are tackling these challenges by enhancing transparency and safeguarding patient information during model development.

Future Directions

The upcoming advancements of AI in oncology are centered on:

Transparent and Reliable AI: Improving the clarity of models to gain trust from clinicians.

Synergy with Genomic Medicine: Merging AI approaches with CRISPR technology and molecular profiling for highly individualized treatment.

Digital Twin Innovations: Creating virtual representations of patients to simulate therapies and predict outcomes.

Collaboration Between Humans and AI: Enhancing the role of oncologists with AI support to promote safe and ethical practices

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