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ARTIFICIAL INTELLIGENCE IN CANCER DIAGNOSIS, THERAPY, RESEARCH, AND DRUG DEVELOPMENT

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ABSTRACT

Artificial intelligence (AI) is transforming management of cancer by improving the speed and accuracy in early detection of pre-cancerous and cancerous lesions, supporting the clinicians in refining risk prediction, and enabling equitable screening at scale.Artificial intelligence (AI), and in particular its subfield of machine learning, is ideal for deciphering patterns in large datasets and offers unique opportunities for advancing precision oncology. In today's world, AI has become an inseparable part of our present and future. Artificial intelligence (AI) plays a considerable transformative role in cancer prevention and early cancer detection; with its potential, it significantly improves survival rates and reduces the burden on healthcare systems. It has substantially changed the standard diagnostic approach by switching it from reactive, symptom-based diagnosis to proactive, AI-assisted screening. Its algorithms are designed to analyse medical images (X-rays, CT scans, MRIs, and mammograms) to detect, localize, and segment tumour-like structures far more efficiently and with higher accuracy. Integrating Artificial Intelligence (AI) with radiologists can help improve patient outcomes & reduce diagnostic delays. Artificial intelligence is revolutionizing cancer research by drastically accelerating early detection, drug discovery, and tumour analysis. AI is already becoming an indispensable ally in the fight against cancer.

INTRODUCTION

Innovations in oncology have driven a decline in cancer mortality rates by 33% in the last 32 years. The concurrent rise of precision medicine techniques – some of which are based on artificial intelligence (AI) – has enabled oncology clinicians to better identify previously unnoticed patterns in radiological scans, predict disease progression, offer tailored therapies, and suggest clinical trial eligibility. (1)

Artificial intelligence describes the creation of data-driven, self-operating algorithms for problem-solving. Two key terms central to AI are machine learning (ML) and deep learning (DL). Machine learning is a subset of AI and refers to algorithms that automatically learn and adapt from data without explicitly being programmed (2)

Breast cancer screening is another clinical context where AI diagnostic aids have been beneficial in identifying disease processes earlier. Screening efforts have evolved with improvements in radiological equipment and public outreach in the last few decades, helping to decrease breast cancer mortality by over 43% since 1989 (3)

These datasets offer unprecedented insights into cancer biology but also present challenges: their analysis is time-consuming, labor-intensive, and difficult for humans due to the high complexity and subtle patterns within the data. (4)

This explosion of big data has positioned AI as an essential tool in cancer research owing to its ability to process large datasets without fatigue and with greater accuracy and efficiency than human researchers and conventional statistical models. (5)

AI's ability to uncover patterns and correlations that might otherwise remain undetected further underscores its transformative role in advancing cancer research (6)

Thoracic imaging has particularly benefited from the development of AI and deep learning, and is the most frequently targeted area for AI software (7)

One of the foundational techniques in AI is regression analysis, including linear and logistic regression. These statistical methods enable the prediction of outcomes based on input variables known as features. Linear regression predicts continuous outcomes, while logistic regression is used for binary outcomes, such as the presence or absence of a disease. These models are integral to medical research and practice, forming the basis for many clinical decision-making processes (8).

As AI has advanced, more sophisticated algorithms have been developed to handle complex datasets. Clustering algorithms, like k-nearest neighbors, group similar data points, aiding pattern recognition within patient populations. Dimensionality reduction techniques, such as Principal Component Analysis (PCA) and Singular Value Decomposition (SVD), simplify large datasets by reducing the number of variables, making it easier to visualize and interpret data without significant loss of information (9).

Decision trees are widely used in predictive modeling for their ability to model decisions and their possible consequences. These have evolved into more robust methods like random forests and gradient boosting machines (e.g., XGBoost), which improve predictive performance by combining multiple decision trees to reduce overfitting and enhance accuracy. These ensemble methods are particularly effective in analyzing tabular medical data, such as electronic health records, to predict patient outcomes and inform treatment strategies (10).

The development of neural networks has been pivotal in AI, leading to the emergence of deep learning. These networks, inspired by the human brain's architecture, can model complex, non-linear relationships in data. In medical imaging, Convolutional Neural Networks (CNNs) have revolutionized computer vision tasks by enabling machines to interpret visual data accurately. CNNs are extensively used in analyzing radiological images, assisting in the detection and diagnosis of conditions such as tumors and fractures (11).

Modern artificial intelligence (AI) tools built on high-dimensional patient data are reshaping oncology care, helping improve goal-concordant care, reduce cancer mortality rates, and increase workflow efficiency and the scope of care.(12)

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AI software that matched the performance of human radiologists when acting as the second reader of mammography scans can streamline breast cancer diagnoses by cutting radiologists' workloads by at least 30% (14).

Beyond algorithm development and reader studies, validating the performance of an AI diagnostic tool in prospective clinical trials is critical for evaluating its effective integration and safety in real-world settings. The Mammography Screening with Artificial Intelligence (MASAI) study in Sweden is the first randomized controlled trial to assess how AI CAD tools can be integrated safely into clinical workflows (15)

Precision Oncology Rests on a Simple But Demanding Premise

Every tumour is biologically unique, and treatment should be matched accordingly.

Because every tumour features a distinct molecular and genetic fingerprint, modern oncology relies on precision testing rather than one-size-fits-all treatments. Analysing a tumour's specific DNA, biomarkers, and cellular micro-environment helps map out targeted therapies and immunotherapies tailored to the exact genomic profile.

As new biomarkers emerge, molecular profiling matures, and cutting-edge modalities like AI-driven analytics and cellular immunotherapy gain traction, these strategies will increasingly shape cancer care—offering more personalized and effective treatments across a growing spectrum of tumor types worldwide Genomic profiling, radiographic inter-pretation, pathology review, and treatment matching each generate more data than any single clinician can synthesise manually.

AI is best understood not as a replacement for oncological judgement, but as the intelligence layer that makes precision oncology *scalable* -turning what was once boutique, academic-centre medicine into something deliverable anywhere.

AI-matched targeted therapy has been associated with a 68% improvement in progression-free survival over standard chemotherapy in non-small-cell lung cancer, and AI tumour board recommendations have shown 89% concordance with expert multidisciplinary panels across complex global cases.

AI and Precision Diagnostics:

"*Artificial Intelligence Advances for Medical Computer-Aided Diagnosis*" provides excellent and recent research findings for AI-based medical diagnosis.

Artificial Intelligence is reshaping precision diagnostics, serving as the foundational entry point for proactive healthcare.

By fusing multimodal biomedical data—such as genomics, digital pathology, and medical imaging—AI tools unlock earlier, more accurate diagnoses and hyper-personalized treatment pathways

Diagnosis is where AI's impact is most immediately measurable. In digital pathology, deep-learning heatmaps applied to prostate biopsies have cut detection time by roughly 65%. In radiology,

AI-enhanced staging models have reached approximately 93% accuracy in lung cancer staging, compared with roughly 72% using clinical guidelines alone.

Radiogenomic AI now links imaging phenotypes to underlying tumour genetics non-invasively, and outcome-forecasting models can predict clinically significant radiation toxicity with strong discriminative accuracy.

Liquid biopsy has matured into one of the most consequential diagnostic tools in oncology. A simple blood draw can now detect circulating tumour DNA, circulating tumour cells, and exosomes, achieving up to 95% concordance with tissue biopsy for actionable mutations - with a materially faster turnaround. Population-level screening is following the same trajectory:

AI-guided mammography has found roughly 17.6% more cancers, and multi-cancer early detection (MCED) platforms can now screen for 50 or more cancer types from a single 10ml blood sample, many of which currently have no standard screening pathway.

Multimodal data can help healthcare providers monitor the progression of a condition over time, allowing for more effective treatment and management of chronic diseases. Meanwhile, using multimodal medical data, Explainable XAI-based healthcare providers can detect potential health problems earlier, before they become serious and potentially life-threatening (17)

Moreover, AI-powered Clinical Decision Support Systems (CDSSs) could provide real-time assistance and support to make more informed decisions about patient care.

XAI tools can automate routine tasks, freeing healthcare providers to focus on more complex patient care.

The future of AI-based medical diagnostics is likely to be characterized by continued growth and development, as OpenAI (18)

More advanced AI technologies are being introduced into the research domain, such as quantum AI (QAI), to speed up the conventional training process and provide rapid diagnostic models (19)

How AI Detects Breast Cancer?

The process of AI detecting breast cancer involves the utilization of software(machine) & application of algorithms on datasets of labeled images, & there by acquiring distinguishing features of cancerous tissues.

Mammography has long been the gold standard for breast cancer screening & is highly effective in detecting abnormalities in breast tissue that could be cancer, long before patients experience lumps & other symptoms. But mammography is not 100% accurate & needs additional imaging modalities at times, like ultrasound & MRI. This is especially true in people who have dense breasts or because they have certain risk factors(gene mutations/family history) Still, mammography & other screening tools undoubtedly save lives. But needs to be raised to accurate detection/ diagnosis levels, where in the role of AI comes into play.

Integration of AI & Radiologist Findings
Algorithms can analyze large amounts of data and identify patterns that humans might miss, which can help radiologists make more accurate diagnoses. AI can also help radiologists understand the patient's condition better, & can be used for tasks like cancer screening, detection, diagnosis, and treatment.

DRAWBACK
Some studies say that AI doesn't always work well with radiologists, & that the impact of AI can vary from radiologist to radiologist.

Some setbacks to AI integration include time delays, additional work steps, & unstable AI performance. To achieve the benefits of AI, it is important to design tools that are suited to the needs of individual radiologists.

The integration of AI with RIS has the potential to revolutionize radiology practices. By enhancing diagnostic accuracy & streamlining workflow & efficiencies, AI can assist radiologists in providing patients with the best possible care. The future of radiology is bright with the integration of AI with Radiology reporting services.

How is AI used in Radiology?
Self-learning artificial intelligence algorithms are used to analyze medical images in the fields of X-rays, CTs & MRI scans & assist radiologists.

Cervical Cancer
Recent advances in machine learning and deep learning, coupled with multimodal data fusion, are facilitating integration of genotyping of human papilloma virus (HPV), cytology, colposcopic imaging, molecular biomarkers, and treatment modalities, thereby revealing risk trajectories years before high-grade lesions develop. This narrative review synthesizes evidence from 2018–2025 on applications of AI across screening, diagnosis, multimodal risk modeling, and personalized prognosis prediction of cervical cancer.

2. AI in Cervical Cancer Screening
2.1 AI-assisted Cytology Diagnosis
Papanicolaou test, commonly known as the Pap smear, is the most widely used method of cervical cytology, which plays a critical role in early detection of precancerous and cancerous changes in the cervical cells under the microscope, with sensitivity ranging from 50% to 75% (20)

Liquid-based cytology (LBC) outperformed traditional Pap smears (21)

Given the interobserver variations in the diagnosis and shortage of trained and experienced cytologists, AI-based systems can assist in cytopathology-based diagnosis of precancerous lesions, aiding in better interpretation when compared to conventional manual screening in resource-limited settings.

In a study by Harinath L. et.al. (2025), pap diagnosis assisted by Hologic Genius Digital Diagnostics System (GDDS), an AI–based digital platform for cervical cytology evaluation, demonstrated reduced interobserver variability and enhanced the sensitivity of three cytopathologists who interacted with this system to detect high-grade squamous intraepithelial lesions (HSIL) in Thin Prep Pap tests (22)

The GDDS uses volumetric, digital, whole-slide imaging and overcomes focus limitations in traditional methods. Even though there is a wide gap in the experience of pathologists, with 2 with over 15 years and 1 with more than 3 years, the system demonstrated good sensitivity and strong inter-observer agreement between the pathologists. When ASC-US and above lesions were examined, the sensitivity for the detection of biopsy-confirmed Cervical Intraepithelial Neoplasia (CIN)2+ cases reached 100% (95% CI, 97.4%–100%). The sensitivity remained high, ranging from 96.2% to 97.3% for low-grade squamous intraepithelial lesions (LSIL) and above, and from 84.7% to 92.9% for ASC-H and above, among the three pathologists. Most of the cases were accurately classified with a Kendall W coefficient of 0.722, indicating a high level of consistency between 0.6 and 0.8 across the interpretations done by the three cytopathologists.

AI in Lung Cancer Diagnosis
Lung cancer remains one of the leading causes of cancer-related deaths worldwide, emphasizing the need for improved diagnostic and treatment approaches.

Advanced machine learning models can process massive datasets of medical images, genomics, and clinical records to find subtle patterns, predict patient outcomes, and reduce unnecessary treatments.

Lung cancer diagnosis primarily relies on a CT scan and tissue biopsy, which can lead to misdiagnosis and omissions (23)

Enhancing the sensitivity and specificity of non-invasive biomarkers is crucial. Factors like tumor location, pathology type, metastasis presence, and complications make diagnosis challenging (24)

AI models have become an effective tool in lung cancer diagnosis, improving the accuracy, stability, and efficiency (25)

Diagnostic Imaging
It involves using CT and PET-CT (positron emission tomography-computed tomography) of the chest to find an abnormal mass or tumor in the lung.

Screening using CT scans takes time and is subject to variation between people. With the growing popularity of AI, the medical field has recognized its impact in assisting the use of diagnostic imaging. Ardila et al. developed a deep learning algorithm for detecting lung cancer by low-dose CT scans and achieved a striking AUC of 94.4%.

Another study examined the CT scans of 200 lung nodules with an AUC of 0.72 [27)

Additionally, a study investigated the use of ML for detecting lung cancer by FDG-PET imaging and achieved a sensitivity of 95.9% and 91.5% and a specificity of 98.1% and 94.2% with standard dose and ultralow dose, respectively. These findings indicate that ML modules may help detect lung cancer even at a very low radiation exposure of 0.11 mSv (28)

In a meta-analysis by Liu, the combined sensitivity, specificity, and sum of area under the combined subject operating characteristic (SROC) curve of the AI-aided diagnosis system for lung cancer diagnosis by using CT images were 87%, 87%, and 93%, respectively (29)

AI in Cancer Treatment

AI predicts how individual tumors will respond to therapies, optimizes radiation dosing, and helps accelerate new drug discovery. Artificial intelligence (AI) is quickly becoming a revolutionary and game-changing tool in modern oncology, with promising uses in early diagnosis and drug discovery.

Machine learning (ML), deep learning (DL), reinforcement learning (RL), natural language processing (NLP), and generative models are some of the AI methods that are becoming very important for cancer care.

Precision Targeted Therapy: AI as Matchmaker

More than 100 FDA-approved targeted agents now exist - kinase inhibitors, monoclonal antibodies, antibody-drug conjugates, PARP inhibitors, checkpoint immunotherapies, and CAR-T cell therapies. The clinical bottleneck is no longer drug availability; it is matching. AI-driven genomic profiling pipelines take a patient from biopsy through next-generation sequencing, variant classification, tumour mutational burden and microsatellite instability scoring, biomarker matching, and continuous ctDNA-based monitoring of treatment response.

Perhaps most strikingly, AI is compressing drug discovery itself. Tools built on AlphaFold-class protein structure prediction - recognised by the 2024 Nobel Prize in Chemistry - are accelerating target identification and preclinical design, shrinking timelines that once took over a decade toward a fraction of that. In immunotherapy, where historically only 20–30% of patients respond to checkpoint inhibitors, AI-standardised biomarkers (PD-L1 quantification, TMB, MSI, and gene expression profiling) are meaningfully improving patient selection and reducing inter-pathologist variability.

Precision Radiotherapy: Treating the Tumour of Today

Radiotherapy remains part of the treatment plan for roughly half of all cancer patients, and AI is transforming both planning and delivery. Auto-contouring - long the rate-limiting, most variable step in radiotherapy planning - has been substantially accelerated and standardised by AI. Deep-learning dose prediction and knowledge-based planning are turning planning cycles that once took hours into a matter of minutes, enabling same-day radiotherapy in appropriate cases.

Adaptive, MR-guided radiotherapy (MR-Linac) represents the clearest expression of this shift: daily MRI, AI contouring, plan adaptation, gating, and delivery occur as a single real-time loop. In rectal cancer, AI-adapted protocols have shown a 37% reduction in toxicity alongside high rates of pathological complete response. In prostate cancer, Grade 2+ urinary toxicity has fallen from roughly 28% to 9% with AI-guided adaptive hypofractionation. The underlying principle is one every radiation oncologist will recognise as transformative: the plan adapts to the tumour as it exists *that day*, not the simulation from three weeks earlier.

AI in Cancer Research

Artificial intelligence (AI) is rapidly revolutionizing the landscape of oncological research and the advancement of personalized clinical interventions.

Progress in three interconnected areas, including the development of methods and algorithms for training AI models, the evolution of specialized computing hardware, and increased access to large volumes of cancer data such as imaging, genomics, and clinical information, have converged, leading to promising new applications of AI in cancer research.

Artificial intelligence is revolutionizing cancer research by drastically accelerating early detection, drug discovery, and tumour analysis. advanced machine learning models can process massive datasets of medical images, genomics, and clinical records to find subtle patterns, predict patient outcomes, and reduce unnecessary treatments.

AI tools are opening new avenues across major facets of oncology--

- **Early Detection & Sensors:** Researchers are utilizing AI to design molecular sensors (coated with AI-generated peptides) that detect cancer-linked enzymes from simple urine tests.
- **Advanced Diagnostics:** AI models like CHIEF (Clinical Histology Imaging Evaluation Foundation) analyze digital tissue slides with high accuracy, detecting cancer cells and identifying their tumor origins up to 36% better than previous methods.
- **Drug Discovery:** AI algorithms streamline the process of mapping DNA and identifying targeted therapeutics, shaving months or years off traditional R&D pipelines.
- **Research Verification:** AI models are now actively deployed to screen existing literature, flagging hundreds of thousands of suspicious or low-quality research papers to maintain data integrity in the field

Artificial Intelligence in the Drug Development Process

One of the most crucial aspects of the healthcare system is to develop novel and effective drugs. The drug development process is complex require time and capital investment. The process starts from finding an ideal target for a drug and developing a cost-effective drug molecule via a routine pharmaceutical regulatory cascade. Here, the use of AI not only reduces time but also cuts down costs in the drug development process.

The use of AI in the drug development process provides a platform to compare various databases for efficacy. The AI-based drug development process includes identifying targets for intervention, discovering drug candidates, speeding up clinical trials, and Finding Biomarkers for diagnosing the disease.

In the very first step of drug development, the aim is to understand the biological origin of a disease (pathways) as well as its resistance mechanisms. Then you have to identify good targets (typically proteins) for treating the disease (30)

In the next step, which is finding novel drug molecules, AI plays a vital role. This involves screening a large number – often many thousands or even millions – of potential compounds for their effect on the target (affinity), not to mention their off-target side-effects (toxicity). These compounds could be natural, synthetic, or bioengineered.

Then they blaze through millions of potential molecules and filter them all down to the best options – those that also have minimal side effects. This ends up saving a lot of time in drug design (31)

The third and most important part of the drug development process is clinical trial studies, and here AI is playing a very important role as well. Machine Learning can speed up the design of clinical trials by automatically identifying suitable candidates as well as ensuring the correct distribution for groups of trial participants. Algorithms can help identify patterns that separate good candidates from bad. (32).

CONCLUSION

Artificial intelligence helps in cancer diagnosis, therapy, Research, and Drug development. Artificial intelligence tells us what to do with that knowledge — faster, more consistently, and increasingly at global scale. The evidence across diagnostics, targeted therapy, radiotherapy, surgery, and prevention now points in the same direction: earlier detection, better-matched treatment, fewer complications, and more equitable access. Despite remarkable advances in surgery, chemotherapy, immunotherapy, and precision oncology, the global incidence of cancer continues to rise. Artificial intelligence is revolutionizing cancer research by drastically accelerating early detection, drug discovery, and tumour analysis.

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