e-ISSN: 2320-4230, p-ISSN: 2961-6085

Journal of Drug Discovery and Therapeutics

Available Online at www.jddt.in

CODEN: - JDDTBP (Source: - American Chemical Society)

Volume 13, Issue 6; 2025, 19-25

Artificial Intelligence in Cancer: Transforming Diagnosis, Treatment and Care

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Received: 05-09-2025 / Revised: 24-09-2025 / Accepted: 28-10-2025
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Conflict of interest: No conflict of interest.

Abstract:
AI has become a vital part of today's medical technology, offering innovative ways to identify, manage, and monitor cancer by using data-driven computational models the expanding role of AI in oncology, covering diagnostic imaging, personalized therapy, drug discovery, patient monitoring, and ethical considerations. Artificial Intelligence (AI) is revolutionizing cancer care by enhancing diagnosis, treatment, and patient management. AI-powered tools analyze complex medical data from imaging, genomics, and pathology to detect cancers earlier and with greater accuracy. In treatment, machine learning models support personalized therapy planning, predict treatment responses, and accelerate drug discovery. AI also improves patient care through continuous health monitoring, virtual assistance, and predictive analytics that enable timely interventions. Despite challenges such as data privacy, bias, and regulatory concerns, AI continues to advance toward more precise, efficient, and patient-centered oncology. By integrating AI across all stages of cancer management, healthcare is moving closer to an era of truly personalized and data-driven cancer care.

Keywords: Artificial Intelligence, Oncology, Machine Learning, Deep Learning, Cancer Diagnosis, Precision Medicine, Healthcare Technology.

Introduction

Cancer continues to rank among the most life-threatening diseases worldwide, affecting millions each year despite advances in prevention and therapy. The main barriers to effective cancer control include delayed diagnosis, limited therapeutic precision, and recurrence after treatment. Artificial Intelligence—a technology capable of mimicking human cognitive processes—offers solutions to these long-standing challenges. By processing enormous volumes of heterogeneous medical data. In oncology, AI systems integrate medical imaging, genomic sequencing, laboratory data, and clinical records to create predictive models for diagnosis and prognosis. These capabilities mark a paradigm shift from experience-based to data-driven cancer care. Machine learning helps physicians discover early disease signs often missed in standard examinations, while deep learning models analyze scans and reports to deliver more accurate predictions. Traditional therapies—

surgery, chemotherapy, and radiotherapy—have saved countless lives but remain limited by non-specificity and side effects. AI augments these modalities by analyzing patient profiles to determine which interventions will be most effective for each individual. This personalized approach reduces toxicity, minimizes cost, and enhances overall survival. India has begun deploying AI-enabled screening tools for breast and cervical cancer in rural areas, providing early detection where healthcare resources are scarce.

Understanding Artificial Intelligence in Oncology

AI in oncology is built upon the convergence of computer science, statistics, and medical research, employing algorithms that mimic human reasoning but on an exponentially larger scale. The key branches include**:**

Machine Learning (ML)

Machine Learning involves training algorithms to recognize complex patterns from data. In oncology, ML systems use supervised learning to classify tumor types, unsupervised learning to identify new cancer subgroups, and reinforcement learning to optimize treatment protocols. ML models like Support Vector Machines (SVMs), Random Forests, and Gradient Boosting have proven effective in predicting tumor stage, metastasis potential, and survival probabilities.

Deep Learning (DL)

Deep Learning, a subset of ML, utilizes artificial neural networks composed of multiple processing layers. Convolutional Neural Networks (CNNs) excel at interpreting images from MRI, CT, and histopathology slides. For instance, CNN-based diagnostic systems in lung cancer detection can achieve over 95% sensitivity—comparable to expert radiologists. Recurrent Neural Networks (RNNs) are also used to interpret time-series clinical data such as patient vitals or treatment responses**.**

Natural Language Processing (NLP)

NLP enables machines to read and interpret text data, extracting useful insights from electronic health records, research publications, and pathology reports. NLP models, including transformer-based systems like BioBERT and MedGPT, can summarize medical histories and identify correlations between symptoms, biomarkers, and clinical outcomes.

When combined, these branches create multi-modal AI models that integrate radiological, genomic, proteomic, and clinical data into unified predictive frameworks. This integration enables holistic insights into cancer biology and patient response, improving consistency, transparency, and clinical decision support.

AI in Cancer Diagnosis

Early diagnosis remains the cornerstone of successful cancer management. AI-driven diagnostic technologies have shown remarkable accuracy and speed in detecting malignancies.The diagnostic process has been transformed by AI's ability to detect patterns that human eyes may miss. AI systems now analyse medical scans to detect even minor abnormalities, and research projects have shown that such tools can sometimes outperform human specialists in diagnostic accuracy.

AI also supports radiomics, a field that quantifies imaging features and links them with clinical outcomes. These quantitative biomarkers provide a deeper understanding of tumour heterogeneity and aggressiveness. Furthermore, predictive AI models assess lifestyle, heredity, and genomic data to calculate an individual's probability of developing certain cancers. Early identification of high-risk individuals allows for timely screening and preventive measures. Unlike conventional diagnostics, which are time-consuming and subjective, AI offers speed, scalability, and objective precision

Imaging and Radiomics

Radiomics—the quantitative extraction of imaging features—has gained prominence with AI integration. Algorithms analyse thousands of imaging biomarkers (e.g., tumour texture, shape, density) from CT, MRI, and PET scans to predict tumour aggressiveness and metastatic potential. For example, Google DeepMind's AI demonstrated superior performance in identifying breast cancer from mammograms, reducing false negatives by 9.4%.

Digital Pathology and Histopathomics

AI has revolutionized pathology by digitizing and analysing tissue slides. Systems like PathAI and Paige.AI employ DL to recognize minute cellular abnormalities, grade tumours, and quantify immune cell infiltration.

These models assist pathologists in diagnosing complex cancers such as lymphoma and melanoma with higher reproducibility.

Molecular and Genomic Diagnosis

AI assists in interpreting large-scale genomic datasets to identify oncogenic mutations and actionable targets. Predictive genomic models can detect BRCA1/2 mutations, KRAS alterations, or EGFR amplifications, guiding precision treatment**.**

Predictive Risk Profiling

Beyond existing cancers, AI models evaluate individual risk based on hereditary, lifestyle, and environmental factors. Systems like CanRisk integrate genetic and family history data to predict breast and ovarian cancer susceptibility, supporting early intervention**.**

AI in Personalized Cancer Treatment

Precision oncology focuses on tailoring treatment to individual tumour profiles. AI enables this personalization through complex data integration and real-time feedback mechanisms.AI plays a central role by integrating multi-omics data—genomic, proteomic, and metabolomic—to predict treatment response.

Algorithms evaluate how tumours react to different drugs, guiding clinicians toward the most effective regimens while minimizing unnecessary toxicity. Projects like The Cancer Genome Atlas (TCGA) and International Cancer Genome Consortium (ICGC) have produced vast genomic datasets that AI uses to identify actionable mutations. Clinical initiatives such as NCI-MATCH and ASCO TAPUR demonstrate the success of matching therapies to molecular alterations rather than tumour location.

AI further aids adaptive therapy, where treatment parameters are adjusted dynamically according to patient feedback and real-time data. In immunotherapy, AI predicts which patients will benefit from checkpoint inhibitors, sparing others from ineffective and expensive interventions.

The emergence of liquid biopsies, which detect circulating tumour DNA (ctDNA) in blood samples, has also benefited from AI. Algorithms interpret ctDNA patterns to monitor disease progression and detect minimal residual disease long before clinical symptoms appear.

Multi-Omics Data Integration

AI correlates data from The Cancer Genome Atlas (TCGA) and International Cancer Genome Consortium (ICGC) to identify patient-specific mutations. ML-based models can match molecular signatures with targeted therapies such as EGFR inhibitors in lung cancer or BRAF inhibitors in melanoma.

Predictive Treatment Modeling

AI predicts therapy response by analyzing previous outcomes, side-effect profiles, and tumor microenvironment characteristics. Reinforcement learning approaches simulate therapy optimization, adjusting dose or drug combinations dynamically.

AI in Immunotherapy

Immune checkpoint inhibitors have transformed cancer therapy, yet their effectiveness varies widely. AI models predict which patients will respond to PD-1, PD-L1, or CTLA-4 inhibitors by analyzing gene expression, tumor mutational burden, and T-cell infiltration.

Liquid Biopsies and ctDNA

AI interprets circulating tumor DNA (ctDNA) patterns to detect minimal residual disease, monitor treatment efficacy, and identify early relapse—offering a non-invasive and real-time method for disease surveillance.

AI in Drug Discovery and Development

Drug discovery is typically time-consuming, but AI accelerates it by digitally modeling how molecules interact and identifying promising compounds more efficiently. Such advancements enable faster identification of new therapeutic targets.

AI also supports drug repurposing, where existing medications are analyzed for new anti-cancer applications, particularly in modulating the tumor microenvironment. In clinical trials, AI enhances patient selection, predicts adverse effects, and automates data analysis. This not only reduces cost and duration but also improves patient safety. Regulatory bodies like the FDA are now considering frameworks for validating AI assisted trials and manufacturing under Good Manufacturing Practices (GMP).

AI drastically shortens the 10–15year cycle of drug discovery.

- Molecular Screening: AI models like AlphaFold predict protein structures, enabling researchers to identify potential drug-binding sites faster.
- Drug Repurposing: By mining existing drug databases, AI identifies new anti-cancer uses for approved drugs—for instance, metformin's repurposing for breast cancer therapy.
- Clinical Trials Optimization: AI enhances patient recruitment by matching trial criteria with EHRs, predicts adverse reactions, and accelerates data monitoring.
- Manufacturing Efficiency: AI systems maintain process quality in biopharmaceutical manufacturing through predictive maintenance and anomaly detection under Good Manufacturing Practice (GMP) compliance.

These advancements not only reduce cost but also democratize access to novel therapies globally.

AI in Patient Monitoring and Survivorship Care

Precision oncology aims to match treatments to each patient's unique biological features. AI extends its utility beyond hospitals into continuous patient care. Machine learning algorithms analyze these data streams to detect early signs of infection or therapy-related toxicity.

Predictive systems can warn physicians of potential hospital readmissions or adverse events before they occur. AI-powered chatbots provide medication reminders, psychological support, and symptom tracking, reducing the burden on clinical staff. Integrating these technologies with telemedicine platforms ensures personalized, proactive, and preventive cancer care.

AI extends beyond treatment into long-term survivorship management.

- Remote Monitoring: Wearables and sensors collect physiological data such as heart rate, sleep, and glucose levels, which AI analyzes to detect side effects or relapse signs early.
- Predictive Care: Predictive models forecast hospital readmissions and adverse events, allowing timely interventions.
- Virtual Companions: AI-powered chatbots (e.g., Replika Health, CancerAid) assist in symptom tracking, medication reminders, and emotional counselling.
- Palliative and End-of-Life Care: AI assesses pain levels, suggests dosage adjustments, and supports communication among caregivers, promoting holistic, patient-centered care.

Ethical, Legal, and Social Challenges

While AI holds immense promise, it also raises complex ethical and legal issues. Data privacy remains paramount since AI models rely on large volumes of sensitive patient information.

Strong encryption, anonymization, and informed consent are vital to protect confidentiality. Ethical challenges include limited transparency in AI decision-making, potential data bias, and unclear accountability when AI errors cause harm.

Regulatory authorities must establish clear frameworks to define responsibility, ensure fairness, and maintain public trust.

Despite rapid progress, several challenges must be addressed before AI achieves full clinical integration.

- Data Privacy and Security: Large-scale medical data must comply with data protection laws such as GDPR and HIPAA. Federated learning offers solutions by allowing decentralized model training without data exchange.
- Algorithmic Bias: Models trained on homogenous data may underperform across diverse populations. Inclusion of multi-ethnic datasets is vital.
- Explainability: The "black box" nature of DL systems limits clinician trust. Explainable AI (XAI) frameworks aim to provide transparency by visualizing decision pathways.
- Regulatory Oversight: Agencies like the FDA and EMA are developing dynamic regulatory frameworks for AI-based diagnostics, demanding traceability and validation.
- Ethical Governance: Ensuring human oversight, informed consent, and equitable access remains essential to prevent misuse or inequitable outcomes.

Future Prospects of AI in Oncology

The next decade will see AI integrate seamlessly into every stage of cancer care—from prevention to palliative treatment. Digital twin models will simulate patient responses, allowing oncologists to test therapies virtually before clinical application.

Explainable AI (XAI) will make decision processes transparent and interpretable, strengthening clinician confidence.

AI's combination with genomics and radiomics will uncover novel biomarkers, predict resistance pathways, and accelerate drug discovery. Advances in federated learning and multi-modal data fusion will drive global collaboration while maintaining patient privacy. By transforming cancer care from reactive to predictive, AI promises earlier detection, personalized intervention, and continuous monitoring that improve both longevity and quality of life. Conclusion Artificial Intelligence is redefining the landscape of oncology through its ability to process massive datasets, identify complex biological relationships, and support evidence-based decisions. Its adoption has improved diagnostic accuracy, personalized treatment, and patient monitoring while reducing human error and healthcare costs. Despite ethical and regulatory challenges, the integration of AI into cancer care remains an essential step toward equitable, efficient, and patient-centered healthcare. Ongoing collaboration between clinicians, technologists, and policymakers will ensure that AI's benefits are distributed fairly and responsibly. The future of oncology lies in harmonizing human expertise with machine intelligence to achieve optimal patient outcomes.

The future of AI in cancer care is marked by integration, transparency, and collaboration.

- Digital Twins: Virtual patient replicas will simulate biological responses to therapies before clinical administration.
- Explainable AI (XAI): Enhancing model interpretability will strengthen clinician trust and patient safety.
- Federated and Multi-Modal Learning: These approaches will facilitate global collaboration while preserving data privacy.
- Integration with Genomics and Radiomics: Combined insights will identify new biomarkers and predict drug resistance mechanisms.

Ultimately, AI will transition cancer care from reactive to proactive, ensuring earlier diagnosis, personalized treatment, and continuous monitoring that improve survival and quality of life.

Conclusion

Artificial Intelligence is reshaping oncology by enabling the integration of complex biological, clinical, and imaging data into actionable insights. Its role in diagnosis, treatment personalization, and patient monitoring has already demonstrated measurable improvements in precision, efficiency, and outcomes.

While ethical, legal, and infrastructural challenges persist, the collaboration among clinicians, data scientists, and policymakers is paving the way for a responsible AI-driven future. By harmonizing human expertise with computational intelligence, AI promises to deliver truly personalized, equitable, and transformative cancer care.

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