



Place of Artificial Intelligence in Oncology: Literature review and Perspectives

Soufiane Khelifi Touhami^{1*}, Abdelaziz Ammari², Mohamed Djerouni³, Fayez Althobiti⁴, Abdulrahmane Alrubayee⁵.

1,3,4,5. Medical Oncology consultant at King Abdulaziz Specialist Hospital Taif Saudi Arabia.

2- Professor of Medical Oncology at University 3 of Constantine Algeria.

***Correspondence to:** Soufiane Khelifi Touhami, Medical Oncology consultant at King Abdulaziz Specialist Hospital Taif Saudi Arabia.

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Artificial Intelligence and Healthcare

Artificial Intelligence (AI) is a subfield of computer science concerned with algorithms that perform tasks typically associated with human cognition. AI has been applied to medical problems for many years, but accelerated adoption in healthcare is now motivated by a growth in data volume and comprehensiveness, improvements in computational power, and an increase in innovative software developers. Modern AI technology can provide significant insight and benefit by processing a diverse set of data types related to a problem domain. Beyond the capability to recognize patterns in data, AI algorithms can synthesize large volumes of information from multiple sources quickly. In healthcare, common applications include identifying conditions, risk factors, or patterns to support clinical decision-making, population health, and discovery. Cancer is a broad class of devastating diseases that grows exponentially in complexity as it progresses, creating a difficult analytical space for reasoning and management. Ongoing work suggests that AI may be particularly well suited to meeting this challenge, but widespread impact in the clinical domain remains elusive.

Artificial Intelligence and Oncology

Cancer is a leading cause of death worldwide and is projected to become more common with age. This outlook highlights the importance of secondary prevention through early diagnosis and improved treatment two areas that have undergone significant transformation aided by artificial intelligence. AI enhances early diagnosis by enabling automated, improved accuracy in cancer identification. It supports improved patient outcomes through treatment planning, tumor detection, segmentation, and grading. Oncology encompasses the study and treatment of malignant growths formed by the convergence of uncontrolled proliferation, diminished apoptosis, and altered cell senescence mechanisms. Cancer can arise within almost all tissue types and is divided into various groups. Individual tissue types may be associated with a variety of different tumors that span a wide clinical and biological spectrum and have different prognoses. These include benign and malignant categories, regimes of clinical behavior, and live span. Following appropriate regenerative, proliferation and differentiation mechanisms, a variety of changes are associated with the formation of the cancerous state which include cellular features such as increased adaptability, tissue invasion and systemic spread. Treatment options for oncology patients include radiotherapy, surgery and systemic therapies which can either be in the form of chemotherapy, targeted agents or immunotherapy.

Artificial Intelligence and Cancer Diagnosis

Artificial Intelligence in Image Analysis and Radiology : AI driven image analysis in oncologic radiology enhances detection, characterization, and monitoring of malignancies, supports precision medicine, and optimizes workflow. While promising, successful clinical integration requires addressing challenges related

to data quality, interpretability, and regulatory compliance. Ongoing research and collaboration between clinicians, data scientists, and industry are essential for realizing the full potential of AI in oncologic imaging [1].

Pathology and Histopathology : Artificial intelligence is increasingly integrated into pathology and histopathology, transforming diagnostic workflows and research. AI, particularly deep learning, enables automated analysis of digital whole-slide images, supporting tasks such as tumor detection, grading, and subtyping with high accuracy and reproducibility. AI-driven image analysis can reduce interobserver variability, improve efficiency, and assist in quantifying biomarkers and therapeutic targets [2].

Radiomics and computational pathology approaches allow extraction of high-dimensional features from tissue images, supporting prognostication and precision medicine. AI also facilitates quality control, triage, and educational applications. However, challenges remain regarding data standardization, model interpretability, external validation, and regulatory ethical considerations. Ongoing research focuses on explainable AI and robust clinical integration [3].

Artificial Intelligence and Cancer Treatment Planning

Artificial intelligence is increasingly utilized in cancer treatment planning, particularly in radiation oncology and systemic therapy selection. AI algorithms especially those based on machine learning and deep learning can automate and optimize complex planning tasks, such as tumor and organ-at-risk segmentation, dose distribution prediction, and plan quality assessment [4].

These systems improve efficiency, reduce interobserver variability, and can generate treatment plans that match or exceed the quality of those produced by human experts. AI also supports individualized therapy by integrating multimodal data (imaging, pathology, genomics) to predict treatment response and personalize regimens. Despite these advances, challenges remain regarding data quality, model interpretability, and clinical integration[5].

Machine Learning Algorithms in Oncology

Machine learning (ML) algorithms are increasingly utilized in oncology to enhance cancer detection, diagnosis, prognosis, and treatment personalization. Supervised learning methods such as support vector machines (SVM), random forests, and deep learning (especially convolutional neural networks, CNNs) are widely applied to imaging, pathology, and multi-omics data for tumor classification, segmentation, and risk stratification [6]

Unsupervised learning (e.g., clustering) helps identify novel cancer subtypes and patient groups. ML models can predict treatment response, recurrence risk, and survival, supporting precision oncology. Integration of

ML into clinical workflows improves efficiency and may reduce diagnostic errors, but challenges remain regarding data quality, model interpretability, and generalizability. Ongoing research focuses on explainable AI and robust validation for safe clinical adoption [7]

Natural Language Processing in Cancer Research

Natural language processing (NLP) is increasingly used in cancer research to extract, structure, and analyze information from unstructured clinical text, such as electronic health records (EHRs), pathology reports, radiology reports, and patient narratives [8]

NLP enables automated identification of cancer diagnoses, staging, treatment regimens, adverse events, and outcomes, significantly reducing manual chart review workload and improving data quality for research and clinical decision support. Advanced NLP models, including transformer-based architectures (e.g., BERT, GPT), have improved the accuracy of information extraction, cohort identification, and phenotyping. NLP also facilitates the analysis of patient-reported outcomes, social determinants of health, and patient perspectives, supporting patient-centered research and precision oncology. Key challenges include variability in clinical language, data privacy, generalizability across institutions, and integration into clinical workflows [9].

Predictive Analytics in Oncology

Predictive analytics in oncology leverages statistical and machine learning models to estimate individual patient risk, guide clinical decision-making, and improve outcomes. Risk stratification models use clinical, pathological, imaging, and molecular data to categorize patients by likelihood of recurrence, progression, or treatment response. Survival prediction models, including Cox proportional hazards, random forests, and deep learning approaches, estimate overall or disease-free survival probabilities. These tools support personalized treatment planning, identify high-risk patients for intensified therapy, and inform prognosis discussions. Integration of multi-omics and real-world data is enhancing model accuracy. Key challenges include model validation, interpretability, and integration into clinical workflows [10].

Artificial Intelligence and Clinical Trials

Artificial intelligence is increasingly transforming the design, conduct, and analysis of clinical trials. AI applications include:

Patient Recruitment and Eligibility: AI algorithms efficiently screen electronic health records and other data sources to identify eligible participants, improving recruitment speed and diversity [11].

Trial Design Optimization: Machine learning models assist in adaptive trial designs, endpoint selection, and

sample size estimation, enhancing trial efficiency and informativeness.

Risk Assessment and Monitoring: AI supports real-time safety monitoring, adverse event prediction, and operational risk assessment, enabling proactive risk-based monitoring.

Data Collection and Analysis: Natural language processing and AI-driven tools automate extraction and harmonization of data from unstructured sources, while advanced analytics enable deeper insights from complex datasets.

Patient-Reported Outcomes: AI-powered chatbots and digital tools facilitate real-time collection and analysis of patient-reported outcomes, supporting personalized and data-driven decision-making [12].

Drug Development: AI accelerates drug discovery, repurposing, and biomarker identification, streamlining the transition from preclinical to clinical phases[13].

Ethical Considerations in Artificial Intelligence Applications

AI applications in healthcare exemplify the technological revolution that can advance cancer care and research as one of the most promising domains for them. By adopting ethical guidelines and open communication with the end-user, ethical challenges initially encountered in AI applications may be addressed and even outweighed by the benefits of their implementation [14]

Regulatory Challenges and Frameworks

Artificial intelligence in oncology presents unique regulatory challenges due to its complexity, adaptive learning capabilities, and integration into clinical decision-making. Key issues include ensuring safety, efficacy, transparency, data privacy, and ongoing performance monitoring. Regulatory frameworks must address algorithm validation, bias mitigation, explainability, and post-market surveillance.

FDA Guidelines:

The U.S. Food and Drug Administration (FDA) regulates AI-based medical devices and software as a medical device (SaMD) primarily through risk-based pathways (510 k, De Novo, Premarket Approval). The FDA emphasizes a “total product lifecycle” approach, requiring robust premarket validation, Good Machine Learning Practices (GMLP), and real-world performance monitoring. The FDA’s Digital Health Center of Excellence and AI/ML-Based SaMD Action Plan provide guidance on transparency, algorithm change protocols, and post-market oversight. For oncology, the FDA has issued specific guidance on clinical trial design and accelerated approval pathways for AI-enabled therapeutics and diagnostics [15].

International Regulations:

The European Union (EU) regulates AI in medical devices under the Medical Device Regulation (MDR) and In Vitro Diagnostic Regulation (IVDR), with additional requirements for transparency, human oversight, and risk management. The EU’s proposed AI Act introduces a risk-based framework for all AI systems, including

those in healthcare. Other jurisdictions (e.g., Canada, Japan, Australia) are developing or updating regulatory frameworks to address AI's unique risks, often emphasizing harmonization with international standards (e.g., IMDRF, ISO/IEC) [16].

Case Studies of Artificial Intelligence in Oncology

Artificial intelligence has achieved several successful implementations in oncology, particularly in the domains of cancer detection, diagnosis, prognosis, and treatment planning:

Artificial Intelligence in Imaging and Pathology: Deep learning models, especially convolutional neural networks (CNNs), have demonstrated high accuracy in detecting and classifying tumors in radiology (e.g., mammography, CT, MRI) and digital pathology slides. AI-based systems are now FDA-approved for breast cancer screening and lung nodule detection, improving sensitivity and workflow efficiency [17].

Artificial Intelligence in Risk Stratification and Prognosis: Machine learning algorithms are used to predict recurrence risk and survival in breast, lung, and prostate cancers, supporting personalized treatment decisions.

Radiotherapy Planning: AI-driven auto-segmentation tools streamline target and organ-at-risk delineation, reducing inter-observer variability and planning time.

Clinical Decision Support: AI models integrate multi-omics, clinical, and imaging data to recommend individualized therapies, including immunotherapy response prediction and molecular subtyping.

Clinical Trials: AI facilitates patient matching for oncology trials by rapidly screening electronic health records for eligibility, increasing enrollment efficiency and trial diversity.

These implementations have led to improved diagnostic accuracy, workflow efficiency, and more personalized care, though ongoing validation and oversight remain essential [18].

Future of Artificial Intelligence in Oncology

Future Trends in AI and Oncology: Emerging Technologies and Integration with Other Disciplines –

Short Summary

Artificial intelligence in oncology is rapidly evolving, with several future trends poised to transform **cancer** care:

Emerging Technologies:

Multimodal AI: Integration of data from radiology, pathology, genomics, and clinical records enables comprehensive tumor characterization and more accurate prediction of treatment response and outcomes.

Radiogenomics and Radiomics: AI-driven analysis of imaging features linked with molecular and genetic profiles supports non-invasive tumor subtyping and personalized therapy selection.

Self-supervised and Generative Models: These advanced machine learning approaches can uncover novel

biomarkers, automate feature extraction, and generate synthetic data for rare cancer types, improving model robustness.

Real-time and Edge AI: Deployment of AI models at the point of care (e.g., in operating rooms or radiology suites) allows for immediate decision support and workflow optimization.

AI in Drug Discovery: Machine learning accelerates target identification, compound screening, and biomarker discovery, streamlining the development of new cancer therapies [19].

Integration of Artificial Intelligence with Other Disciplines:

Bioinformatics and Multiomics: AI is increasingly used to analyze complex multiomics datasets (genomics, transcriptomics, proteomics, metabolomics), advancing precision oncology and biomarker discovery.

Digital Pathology and Computational Pathology: AI enables high-throughput, reproducible analysis of histopathology slides, supporting diagnostic consistency and novel insights into tumor biology.

Interdisciplinary Collaboration: AI fosters collaboration between oncologists, radiologists, pathologists, geneticists, data scientists, and engineers, driving innovation in translational research and clinical practice.

Cardio-oncology and Other Subspecialties: AI is being applied to predict and manage cancer therapy-related toxicities, such as cardiotoxicity, integrating oncology with cardiology and other specialties [20].

Key Challenges and Directions:

Future progress depends on addressing data quality, model interpretability, regulatory harmonization, and equitable access to AI technologies across diverse healthcare settings.

Challenges and Limitations of Artificial Intelligence in Oncology

AI in oncology offers significant promise but faces notable challenges and limitations:

Technical Barriers:

Data Quality and Heterogeneity: AI models require large, high-quality, and well-annotated datasets. Variability in imaging protocols, electronic health records, and molecular data can limit model generalizability and performance.

Algorithm Bias and Validation: Models may inherit biases from training data, leading to reduced accuracy in underrepresented populations. External validation and robust testing across diverse cohorts are often lacking.

Explainability and Transparency: Many AI models, especially deep learning systems, function as “black boxes,” making it difficult for clinicians to interpret or trust their outputs.

Integration and Interoperability: Seamless integration with existing clinical workflows and electronic health record systems remains a challenge, often requiring significant IT infrastructure and support.

Regulatory and Security Concerns: Ensuring ongoing safety, efficacy, and data privacy is complex,

especially for adaptive algorithms that evolve over time [21].

Acceptance by Healthcare Professionals:

Trust and Skepticism: Clinicians may be reluctant to rely on AI due to concerns about reliability, loss of clinical autonomy, and lack of understanding of AI mechanisms.

Training and Education: Limited exposure to AI concepts and insufficient training impede adoption and effective use.

Workflow Disruption: Perceived or real increases in workload, workflow changes, and lack of user-friendly interfaces can hinder acceptance.

Ethical and Legal Concerns: Unclear accountability, medicolegal risks, and ethical dilemmas regarding AI-driven decisions contribute to hesitancy [22].

Conclusion

Artificial intelligence is rapidly transforming oncology by improving cancer detection, diagnosis, risk stratification, and treatment personalization. AI-driven tools enhance the accuracy of imaging and pathology interpretation, support precision medicine through integration of complex data, and streamline clinical workflows. While Artificial Intelligence shows promise in optimizing screening and decision-making, challenges remain regarding data quality, model transparency, and clinical integration. Continued research, validation, and multidisciplinary collaboration are essential to ensure safe, effective, and equitable adoption of Artificial Intelligence in cancer care.

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