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Agentic Artificial Intelligence for Precision Oncology: Autonomous Clinical Decision Systems from Diagnosis to Therapy

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ABSTRACT

Cancer remains one of the leading causes of morbidity and mortality worldwide despite substantial advances in molecular diagnostics, targeted therapeutics, immunotherapy, and precision medicine. The extraordinary biological complexity of malignant diseases, together with rapidly expanding volumes of clinical, radiological, pathological, genomic, and molecular data, has created increasing demand for intelligent computational systems capable of supporting individualized clinical decision-making. Recent developments in agentic artificial intelligence (AI) have introduced a new generation of autonomous clinical systems that extend beyond conventional predictive models by continuously perceiving, reasoning, planning, acting, and learning from dynamic healthcare environments. Unlike traditional AI systems that perform isolated prediction tasks, agentic AI integrates multimodal biomedical information, electronic health records, medical imaging, genomic sequencing, digital pathology, laboratory biomarkers, wearable technologies, and clinical guidelines to autonomously coordinate diagnostic reasoning, therapeutic planning, longitudinal monitoring, and adaptive decision support under physician supervision. Advances in large language models, foundation models, multimodal learning, graph neural networks, reinforcement learning, retrieval-augmented generation, and autonomous AI agents have accelerated the development of intelligent oncology ecosystems capable of supporting cancer diagnosis, molecular characterization, treatment optimization, immunotherapy prediction, adaptive radiation therapy, clinical trial matching, survivorship management, and precision therapeutics. Despite these advances, important challenges remain regarding explainability, algorithmic reliability, interoperability, ethical governance, cybersecurity, regulatory approval, accountability, and safe clinical implementation. This review provides a comprehensive overview of agentic artificial intelligence in precision oncology, highlighting computational foundations, current clinical applications, emerging innovations, and future perspectives for autonomous clinical decision systems across the cancer care continuum.[1]

Keywords: Agentic artificial intelligence, Precision oncology, Autonomous clinical systems, Machine learning, Foundation models, Large language models, Clinical decision support, Personalized medicine, Computational oncology, Multimodal learning.

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1. Introduction

Cancer is a highly dynamic disease characterized by genomic instability, epigenetic alterations, transcriptional dysregulation, immune heterogeneity, metabolic reprogramming, and continuous interactions between malignant cells and the tumor microenvironment. Although precision medicine has transformed oncology through molecular diagnostics and targeted therapies, considerable variability in treatment response and disease progression continues to challenge individualized patient management. Patients with apparently similar histopathological diagnoses frequently experience markedly different clinical outcomes because of complex biological differences that cannot be fully explained by isolated biomarkers.[2]

Modern oncology generates enormous quantities of heterogeneous biomedical information through radiological imaging, digital pathology, genomic sequencing, transcriptomics, proteomics, metabolomics, laboratory investigations, wearable biosensors, electronic health records, and real-world clinical data. While each data source contributes valuable biological insight, integrating these diverse datasets into timely and evidence-based clinical decisions has become increasingly difficult using conventional analytical approaches.[3]

Artificial intelligence has emerged as a transformative technology capable of analyzing complex biomedical information at unprecedented scale. However, most existing AI systems remain task-specific, focusing on isolated activities such as image classification, risk prediction, or molecular analysis. Recent advances in agentic artificial intelligence have expanded these capabilities by enabling autonomous systems that perform sequential reasoning, coordinate multiple computational tools, adapt to evolving clinical circumstances, and support continuous clinical decision-making throughout the patient's cancer journey.[4]

Agentic AI therefore represents an important evolution beyond traditional predictive algorithms, introducing intelligent clinical systems capable of integrating perception, reasoning, planning, execution, and learning into comprehensive precision oncology workflows while maintaining physician oversight and patient safety.[5]

2. Evolution of Artificial Intelligence Toward Autonomous Clinical Systems

The evolution of artificial intelligence in oncology has progressed through several distinct stages. Early clinical decision-support systems relied on rule-based expert systems that used predefined medical knowledge to assist clinicians with limited diagnostic tasks. Although useful for structured decision-making, these systems lacked flexibility and were unable to adapt to newly acquired clinical information.[6]

Machine learning subsequently introduced data-driven predictive modeling capable of identifying statistical relationships between clinical variables and patient outcomes. Algorithms including decision trees, support vector machines, random forests, and gradient boosting substantially improved prediction of recurrence, therapeutic response, survival, and treatment toxicity across multiple cancer types.[7]

Deep learning further transformed oncology by automatically extracting complex hierarchical features from radiological imaging, digital pathology, genomic sequencing, and physiological data. Transformer architectures, multimodal foundation models, and large language models subsequently enabled simultaneous processing of heterogeneous biomedical information while improving contextual reasoning across diverse clinical domains.[8]

The latest evolution involves agentic AI systems capable of autonomous task planning, tool utilization, iterative reasoning, knowledge retrieval, adaptive workflow execution, and continuous learning. Rather than generating isolated predictions, these systems coordinate multiple computational processes to accomplish complex clinical objectives while dynamically responding to changing patient information and healthcare environments.[9]

3. Principles of Agentic Artificial Intelligence

Agentic artificial intelligence differs fundamentally from conventional predictive models because it functions as an autonomous reasoning system rather than a single machine learning algorithm. An AI agent continuously observes its environment, interprets incoming information, establishes goals, formulates action plans, executes decisions through appropriate computational tools, evaluates outcomes, and updates future behavior through iterative learning.[10]

Within precision oncology, these autonomous capabilities enable AI agents to integrate radiological imaging, pathology reports, genomic sequencing, laboratory investigations, medication history, clinical guidelines, scientific literature, and longitudinal patient records into coordinated diagnostic and therapeutic workflows.

Agentic systems employ advanced reasoning frameworks involving planning algorithms, retrieval-augmented knowledge generation, reinforcement learning, memory architectures, and multimodal foundation models. These computational components collectively allow AI agents to perform complex sequential clinical reasoning while adapting continuously to evolving patient conditions.

Importantly, agentic AI is designed to augment physician expertise rather than replace clinical judgment. Human oversight remains essential for validating recommendations, ensuring ethical decision-making, and maintaining accountability in high-stakes medical environments.[11]

4. Computational Architecture of Agentic Oncology Systems

Modern agentic oncology platforms consist of multiple interconnected computational layers that function together as intelligent clinical ecosystems. Rather than relying on isolated predictive algorithms, these systems coordinate diverse computational modules responsible for perception, reasoning, planning, execution, monitoring, and learning.[12]

The perception layer acquires multimodal biomedical information from medical imaging, digital pathology, genomic sequencing, laboratory investigations, wearable biosensors, electronic health records, and patient-reported outcomes. Advanced preprocessing pipelines standardize heterogeneous datasets through image normalization, molecular harmonization, natural language processing, and feature extraction.

Reasoning modules subsequently integrate these diverse information sources using multimodal foundation models, graph neural networks, transformer architectures, probabilistic inference, and knowledge graphs capable of representing biological pathways, clinical guidelines, therapeutic interactions, and molecular mechanisms.

Planning modules generate individualized diagnostic and therapeutic strategies based upon patient-specific objectives, whereas execution modules coordinate computational tools responsible for imaging analysis, genomic interpretation, drug interaction assessment, clinical trial matching, treatment optimization, and longitudinal patient monitoring.

Continuous feedback loops enable autonomous learning from newly acquired clinical information, allowing agentic systems to refine future predictions and therapeutic recommendations as patient conditions evolve.[13]

5. Large Language Models and Foundation Models in Oncology

Large language models (LLMs) and multimodal foundation models constitute the cognitive core of many agentic oncology systems. These models are pretrained using enormous biomedical corpora, scientific literature, clinical documentation, medical imaging, genomic databases, and molecular knowledge resources, enabling generalized reasoning across diverse oncology applications.[14]

Foundation models provide broad biomedical representations that can subsequently be adapted through transfer learning to specialized oncology tasks including radiology interpretation, pathology reporting, molecular diagnostics, treatment planning, clinical documentation, patient communication, and research assistance.

Retrieval-augmented generation further strengthens clinical reliability by allowing agentic systems to retrieve current clinical guidelines, scientific evidence, therapeutic protocols, and institutional knowledge before generating recommendations. This architecture reduces hallucination risk while improving evidence-based clinical reasoning.

As multimodal foundation models continue to mature, they are expected to become increasingly capable of integrating imaging, pathology, genomics, laboratory investigations, wearable technologies, and longitudinal clinical records into unified patient-centered reasoning systems that support precision oncology throughout diagnosis and therapy.[15]

6. Multimodal Data Integration and Clinical Reasoning

The effectiveness of agentic AI depends upon seamless integration of heterogeneous biomedical information into coherent patient-specific knowledge representations. Cancer diagnosis and treatment require simultaneous consideration of anatomical imaging, histopathological findings, molecular alterations, immune characteristics, laboratory biomarkers, medication history, comorbidities, and longitudinal clinical observations.[16]

Multimodal learning enables artificial intelligence to harmonize these diverse datasets through shared computational representations that preserve complementary biological information across multiple data modalities. Graph-based knowledge structures further model relationships among genes, proteins, signaling pathways, therapeutic targets, imaging phenotypes, and clinical outcomes.

These integrated computational representations enable agentic systems to perform sophisticated clinical reasoning that extends beyond isolated prediction tasks. Rather than analyzing individual biomarkers independently, autonomous AI evaluates entire biological and clinical contexts before generating personalized diagnostic hypotheses and therapeutic recommendations.

Continuous incorporation of newly acquired patient information enables these reasoning systems to evolve throughout diagnosis, treatment, follow-up, and survivorship, supporting adaptive precision oncology workflows.[17]

7. Agentic AI in Cancer Diagnosis

Accurate diagnosis represents the foundation of effective precision oncology, and agentic AI significantly enhances diagnostic workflows by autonomously coordinating imaging analysis, pathology interpretation, molecular profiling, laboratory assessment, and clinical documentation.[18]

Deep learning algorithms automatically identify suspicious lesions on computed tomography, magnetic resonance imaging, positron emission tomography, mammography, ultrasound, and digital pathology while large language models synthesize diagnostic reports, compare findings with prior examinations, retrieve relevant clinical guidelines, and generate structured diagnostic summaries.

Agentic systems can coordinate multiple diagnostic tools sequentially, recommending additional imaging studies, molecular tests, or laboratory investigations when uncertainty remains. Such autonomous workflow orchestration reduces diagnostic delays while improving consistency across multidisciplinary oncology practice.

Integration of radiological imaging, digital pathology, molecular biology, and longitudinal clinical information enables comprehensive characterization of tumor biology that supports earlier diagnosis and more individualized patient management.[19]

8. Molecular Oncology and Precision Diagnostics

Precision oncology increasingly depends upon comprehensive molecular characterization of individual tumors. Agentic artificial intelligence accelerates interpretation of genomic sequencing, transcriptomics, proteomics, metabolomics, liquid biopsy, and molecular biomarker analyses through autonomous integration of biological information with current scientific evidence.[20]

Machine learning prioritizes clinically actionable genomic variants, predicts functional consequences of mutations, estimates therapeutic sensitivity, identifies mechanisms of drug resistance, and recommends additional molecular investigations when appropriate. Knowledge graphs integrate molecular pathways with pharmacological databases, enabling AI agents to connect genomic findings directly with targeted therapeutic opportunities.

These computational capabilities substantially improve molecular tumor board workflows by rapidly synthesizing complex genomic reports into clinically actionable precision medicine recommendations tailored to individual patients.[21]

9. Agentic AI for Personalized Treatment Planning

One of the most promising applications of agentic artificial intelligence in precision oncology is personalized treatment planning. Unlike conventional clinical decision-support systems that generate isolated predictions, agentic AI autonomously evaluates multiple therapeutic options by integrating radiological imaging, digital pathology, genomic sequencing, transcriptomics, laboratory biomarkers, comorbidities, medication history, and patient-specific clinical characteristics into comprehensive decision-making frameworks.[22]

Artificial intelligence agents estimate treatment response, recurrence probability, progression-free survival, overall survival, and treatment-related toxicity under various therapeutic strategies. These systems can compare chemotherapy regimens, targeted therapies, endocrine therapy, immunotherapy, radiation schedules, surgical interventions, and multimodal treatment combinations before presenting evidence-based recommendations to multidisciplinary oncology teams.

Because agentic systems continuously incorporate newly acquired patient information, therapeutic recommendations evolve throughout treatment, enabling adaptive precision medicine that reflects the changing biological characteristics of both the tumor and the patient.

10. Autonomous Clinical Decision Support

Agentic AI extends beyond traditional clinical decision support by coordinating multiple clinical tasks within unified autonomous workflows. Rather than functioning solely as predictive software, intelligent agents continuously monitor patient information, retrieve relevant clinical guidelines, interpret laboratory investigations, summarize imaging findings, analyze genomic reports, and generate evidence-based recommendations while maintaining physician oversight.[23]

Natural language processing enables autonomous extraction of clinically relevant information from pathology reports, radiology reports, physician notes, multidisciplinary tumor board discussions, discharge summaries, and scientific literature. These data are integrated into comprehensive patient profiles that facilitate diagnostic reasoning, therapeutic planning, toxicity prediction, and longitudinal disease monitoring.

Interactive dashboards present individualized risk assessments, treatment simulations, prognostic predictions, and recommended clinical pathways in formats that enhance multidisciplinary collaboration while reducing administrative burden and cognitive workload.

11. Agentic AI in Immunotherapy and Precision Therapeutics

Immunotherapy has transformed cancer treatment; however, identifying patients who are most likely to benefit from immune checkpoint inhibitors remains one of the greatest challenges in oncology. Agentic AI integrates genomic alterations, tumor mutational burden, PD-L1 expression, immune-cell infiltration, transcriptomic signatures, digital pathology, radiological imaging, laboratory biomarkers, and clinical variables into comprehensive computational models that support individualized immunotherapy selection.[24]

Artificial intelligence agents characterize the tumor microenvironment by quantifying immune-cell populations, stromal architecture, inflammatory signaling pathways, and spatial cellular organization. Autonomous reasoning systems subsequently compare available therapeutic options while predicting efficacy, toxicity, and long-term outcomes.

These capabilities support optimization of immune checkpoint inhibitors, CAR-T cell therapies, bispecific antibodies, adoptive cellular therapies, cancer vaccines, and combination immunotherapy strategies through continuous learning from both individual patient outcomes and large clinical datasets.

12. Agentic AI in Radiation Oncology and Surgical Planning

Radiation oncology and surgical oncology require complex planning processes involving detailed anatomical evaluation, treatment optimization, and multidisciplinary coordination. Agentic AI enhances these workflows through autonomous integration of imaging, pathology, treatment history, and physiological information.[25]

In radiation oncology, AI agents automatically perform tumor segmentation, organ-at-risk delineation, treatment planning, dose optimization, adaptive replanning, and quality assurance. Sequential imaging obtained during treatment continuously updates computational models, enabling radiation plans to adapt according to evolving patient anatomy and tumor response.

Within surgical oncology, intelligent agents generate three-dimensional anatomical reconstructions, estimate surgical complexity, predict resection margins, evaluate lymph node involvement, assess postoperative complications, and simulate alternative operative strategies. These computational tools improve surgical precision while supporting individualized operative planning.

13. Clinical Trial Matching and Drug Discovery

Agentic AI is transforming oncology research by automating patient identification for precision medicine clinical trials. Autonomous systems compare patient-specific molecular profiles, clinical characteristics, treatment history, and laboratory findings against complex clinical trial eligibility criteria to rapidly identify appropriate investigational therapies.[26]

Artificial intelligence also accelerates drug discovery through analysis of molecular pathways, protein interactions, pharmacological databases, genomic alterations, and systems biology networks. Generative AI models design candidate molecules, predict drug-target interactions, estimate toxicity profiles, and prioritize compounds for laboratory validation.

These technologies reduce development timelines, improve clinical trial efficiency, enhance patient recruitment, and facilitate translation of emerging therapeutics into routine oncology practice.

14. Explainable Agentic AI, Ethics, and Governance

Because agentic AI systems perform increasingly autonomous clinical functions, transparency, accountability, and trust have become essential prerequisites for safe implementation. Explainable artificial intelligence (XAI) enables clinicians to understand how autonomous agents generate diagnostic hypotheses and therapeutic recommendations using saliency maps, attention visualization, SHAP (Shapley Additive Explanations), feature attribution analysis, and counterfactual reasoning.[27]

Several additional challenges remain. Autonomous AI systems must address algorithmic bias, incomplete clinical data, interoperability limitations, cybersecurity threats, patient privacy, informed consent, regulatory approval, liability, and continuous quality assurance. Human oversight remains indispensable to ensure that autonomous recommendations remain clinically appropriate, ethically responsible, and aligned with patient preferences.

Development of transparent governance frameworks, standardized validation protocols, secure computational infrastructure, and international regulatory standards will be essential for responsible deployment of agentic AI within healthcare systems.

15. Future Perspectives

The future of precision oncology will likely involve fully integrated intelligent healthcare ecosystems in which autonomous AI agents collaborate with clinicians throughout every stage of cancer care. Foundation models trained on multimodal biomedical datasets will support generalized reasoning across radiology, pathology, genomics, laboratory medicine, pharmacology, surgery, radiation oncology, and survivorship care.[28]

Digital twins, reinforcement learning, federated learning, wearable biosensors, liquid biopsy, spatial multi-omics, cloud computing, robotic systems, and generative artificial intelligence will further strengthen autonomous clinical reasoning while enabling continuous adaptation to individual patient needs.

Rather than functioning as isolated software applications, future agentic systems are expected to coordinate multidisciplinary oncology workflows, optimize resource allocation, automate routine documentation, facilitate patient communication, and provide continuously evolving evidence-based recommendations that enhance precision medicine.

16. Discussion

Agentic artificial intelligence represents the next major evolution of computational oncology by transforming conventional predictive algorithms into autonomous reasoning systems capable of coordinating diagnosis, molecular interpretation, treatment planning, longitudinal monitoring, and clinical decision support. These intelligent systems integrate multimodal biomedical information with current scientific knowledge, clinical guidelines, and real-world patient data to generate adaptive recommendations throughout the cancer care continuum.[29]

Applications spanning diagnostic imaging, digital pathology, molecular oncology, immunotherapy, radiation therapy, surgical planning, clinical trial matching, drug discovery, and survivorship management demonstrate the extraordinary potential of autonomous AI agents for improving clinical efficiency, diagnostic accuracy, therapeutic precision, and patient outcomes. Nevertheless, successful implementation requires rigorous clinical validation, transparent governance, explainable decision-making, secure data infrastructure, and continuous physician supervision to ensure safe and equitable adoption.

17. Conclusion

Agentic artificial intelligence is redefining precision oncology by introducing autonomous clinical systems capable of integrating radiological imaging, digital pathology, genomics, laboratory biomarkers, electronic health records, scientific literature, and real-time patient information into comprehensive evidence-based clinical workflows.[30]

Unlike conventional AI models that perform isolated prediction tasks, agentic systems continuously perceive, reason, plan, execute, monitor, and learn, enabling adaptive clinical decision-making from diagnosis through therapy and survivorship. As large language models, multimodal foundation models, reinforcement learning, digital twins, federated learning, and computational systems biology continue to evolve, agentic AI is expected to become an essential component of future oncology practice.

Although important scientific, ethical, technical, and regulatory challenges remain, continued collaboration among oncologists, computer scientists, biomedical engineers, healthcare organizations, and regulatory agencies will accelerate the responsible integration of autonomous clinical decision systems into precision cancer care, ultimately improving patient outcomes and advancing the next generation of personalized oncology.

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