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AGENTIC FOUNDATION MODELS FOR PRECISION ONCOLOGY: AUTONOMOUS CLINICAL INTELLIGENCE ACROSS THE CANCER CARE CONTINUUM

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Abstract: Agentic foundation models represent the next evolutionary stage of artificial intelligence (AI) in precision oncology by integrating autonomous reasoning, multimodal clinical intelligence, adaptive decision support, and continuous learning across the cancer care continuum. Unlike conventional AI systems that perform isolated predictive tasks, agentic foundation models coordinate complex clinical workflows through autonomous planning, evidence synthesis, multimodal reasoning, and intelligent collaboration with healthcare professionals under human supervision. Recent advances in multimodal transformer architectures, graph neural networks, self-supervised learning, reinforcement learning, retrieval-augmented generation, and generative artificial intelligence have enabled comprehensive integration of radiological imaging, digital pathology, genomics, transcriptomics, proteomics, metabolomics, epigenomics, spatial biology, laboratory biomarkers, circulating tumor DNA, wearable physiological monitoring, electronic health records, biomedical literature, and longitudinal clinical outcomes into unified computational representations of cancer biology. These intelligent systems support precision diagnosis, biomarker discovery, prognostic prediction, therapeutic optimization, adaptive clinical trials, digital twin simulation, survivorship management, and evidence-based multidisciplinary decision-making. Emerging technologies including multimodal large language models, federated learning, explainable artificial intelligence, cloud-native healthcare platforms, digital health ecosystems, robotics, and autonomous clinical orchestration further strengthen agentic oncology systems by enabling collaborative, privacy-preserving, transparent, and continuously adaptive biomedical intelligence. Despite remarkable technological progress, important scientific, technical, ethical, regulatory, and implementation challenges remain regarding multimodal data harmonization, computational scalability, interoperability, cybersecurity, clinical validation, governance, and equitable implementation. This review provides a comprehensive overview of agentic foundation models for precision oncology, emphasizing autonomous clinical intelligence across the entire cancer care continuum.[1]

Keywords: *Agentic AI, Foundation models, Precision oncology, Autonomous clinical intelligence, Digital twins, Multimodal artificial intelligence, Computational oncology, Clinical decision support, Personalized therapeutics, Precision medicine.*

1. Introduction

Cancer is an extraordinarily dynamic disease characterized by continuous genomic evolution, epigenetic remodeling, immune adaptation, metabolic reprogramming, stromal remodeling, angiogenesis, therapeutic resistance, and intricate interactions among malignant cells, immune populations, vascular structures, extracellular matrix, and host physiology. These interconnected biological processes evolve throughout diagnosis, treatment, recurrence, metastasis, and survivorship, making precision oncology increasingly dependent upon intelligent computational systems capable of integrating

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heterogeneous biomedical information across multiple biological scales.[2]

Modern oncology generates unprecedented quantities of biomedical information through radiological imaging, digital pathology, genomic sequencing, transcriptomics, proteomics, metabolomics, epigenomics, spatial biology, laboratory investigations, circulating tumor DNA, wearable physiological monitoring, physician documentation, electronic health records, biomedical literature, clinical guidelines, and patient-reported outcomes. Although each modality contributes valuable biological insight, isolated interpretation frequently limits comprehensive understanding of evolving cancer biology and personalized therapeutic decision-making.[3]

Agentic foundation models represent a transformative computational paradigm by autonomously coordinating multimodal biomedical reasoning, adaptive workflow management, evidence synthesis, digital twin simulation, and multidisciplinary clinical decision support while maintaining meaningful clinician oversight throughout the cancer care continuum.

2. Evolution of Agentic Artificial Intelligence in Oncology

Artificial intelligence in oncology has evolved from narrow computer-aided diagnostic systems toward intelligent computational ecosystems capable of generalized reasoning and autonomous workflow coordination. Early machine learning algorithms primarily focused on isolated tasks such as lesion classification, pathology interpretation, survival prediction, or molecular biomarker identification. Although clinically valuable, these systems demonstrated limited flexibility, contextual understanding, and adaptability across diverse oncology applications.[4]

Deep learning substantially expanded computational capabilities by enabling automated representation learning from radiological imaging, digital pathology, genomics, and electronic health records. Transformer architectures subsequently revolutionized biomedical AI by enabling contextual understanding across heterogeneous biomedical modalities.

Foundation AI models now acquire transferable biomedical knowledge through large-scale self-supervised learning, while agentic AI extends these capabilities through autonomous planning, adaptive reasoning, intelligent orchestration, and continuous collaboration with clinicians, thereby supporting comprehensive precision oncology.[5]

3. Principles of Agentic Foundation Models

Agentic foundation models differ fundamentally from conventional artificial intelligence because they combine generalized biomedical representation learning with autonomous reasoning, long-term planning, adaptive decision-making, and coordinated execution under human supervision. Rather than performing isolated prediction tasks, these systems dynamically organize complex clinical workflows while integrating multiple specialized computational capabilities into unified clinical intelligence.[6]

Self-supervised learning enables discovery of latent biological relationships without requiring extensive manual annotation, while multimodal transformer architectures align radiological imaging, digital pathology, genomics, transcriptomics, proteomics, metabolomics, epigenomics, laboratory biomarkers, wearable physiological monitoring, physician documentation, patient-reported outcomes, biomedical literature, and longitudinal clinical trajectories within generalized computational embedding spaces.

Graph neural networks characterize biological interactions among genes, proteins, signaling pathways, immune populations, imaging phenotypes, tissue architecture, therapeutic targets, physiological variables, environmental exposures, and clinical outcomes, enabling systems-level reasoning. Reinforcement learning further supports adaptive planning by continuously refining diagnostic and therapeutic strategies according to evolving patient information and clinical outcomes.[7]

4. Computational Architecture of Agentic Oncology Systems

Modern agentic oncology platforms consist of interconnected computational layers responsible for biomedical data acquisition, preprocessing, multimodal representation learning, autonomous

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reasoning, workflow orchestration, digital twin simulation, predictive analytics, knowledge integration, and intelligent clinical decision support.[8]

The acquisition layer continuously integrates radiological imaging, digital pathology, genomic sequencing, transcriptomics, proteomics, metabolomics, epigenomics, spatial biology, laboratory investigations, circulating tumor DNA, wearable physiological monitoring, medication history, physician documentation, patient-reported outcomes, biomedical literature, clinical guidelines, pharmacological databases, and electronic health records. Advanced preprocessing pipelines normalize imaging studies, harmonize molecular datasets, encode clinical narratives using natural language processing, synchronize temporal patient information, and continuously incorporate emerging scientific evidence.

Foundation AI models subsequently generate generalized multimodal embeddings representing molecular biology, tissue architecture, imaging phenotypes, physiological function, environmental exposures, and longitudinal clinical trajectories. Agentic reasoning modules then coordinate specialized computational agents responsible for diagnosis, biomarker interpretation, evidence retrieval, therapeutic planning, toxicity prediction, and clinical workflow optimization.[9]

5. Agentic AI for Precision Cancer Diagnosis

Precision diagnosis represents one of the most important applications of agentic foundation models. Autonomous clinical intelligence integrates radiological imaging, digital pathology, laboratory biomarkers, molecular diagnostics, physician documentation, and biomedical literature into coordinated diagnostic reasoning workflows capable of supporting multidisciplinary oncology practice.[10]

Radiological agents automatically identify suspicious lesions, quantify tumor burden, characterize imaging phenotypes, and perform longitudinal comparisons. Pathology agents evaluate histological architecture, tumor grading, immune microenvironment, mitotic activity, and molecular phenotype prediction. Molecular reasoning agents simultaneously interpret genomic variants, transcriptomic alterations, proteomic signatures, circulating tumor DNA, and therapeutic biomarkers.

These specialized computational agents collaborate under centralized orchestration to generate comprehensive diagnostic summaries while enabling clinicians to validate findings, resolve ambiguity, and incorporate contextual clinical judgment before establishing final diagnoses.[11]

6. Autonomous Therapeutic Intelligence

Precision oncology increasingly requires simultaneous evaluation of molecular biomarkers, genomic alterations, imaging phenotypes, histopathological findings, laboratory investigations, treatment history, performance status, comorbidities, patient preferences, evolving scientific evidence, and clinical practice guidelines. Agentic foundation models synthesize these diverse biomedical modalities into adaptive patient-specific therapeutic strategies through autonomous reasoning.[12]

Dedicated computational agents identify actionable molecular alterations, predict therapeutic responsiveness, estimate treatment-related toxicity, evaluate recurrence risk, synthesize evidence from clinical trials, assess drug interactions, monitor treatment adherence, and recommend individualized supportive care strategies. These coordinated recommendations are subsequently reviewed by multidisciplinary oncology teams that incorporate patient values, healthcare accessibility, socioeconomic considerations, ethical principles, and clinical expertise before implementing personalized therapeutic plans.

This collaborative model substantially improves evidence-based precision therapeutics while preserving clinician responsibility and patient-centered care.[13]

7. Multimodal Clinical Intelligence

Comprehensive autonomous oncology depends upon seamless integration of complementary biomedical modalities into unified computational representations. Radiological imaging provides anatomical and functional characterization of tumors, digital pathology reveals microscopic tissue architecture, while genomics, transcriptomics, proteomics, metabolomics, epigenomics, immunomics, microbiomics, single-cell sequencing, and spatial biology comprehensively characterize evolving molecular mechanisms underlying cancer progression.[14]

Agentic foundation models harmonize these heterogeneous biomedical modalities using multimodal transformers, graph neural networks, biological knowledge graphs, retrieval-augmented generation, and cross-modal attention mechanisms capable of generating adaptive patient-specific representations. Multiple autonomous reasoning agents simultaneously interpret imaging findings, molecular biomarkers, laboratory investigations, wearable physiological monitoring, environmental exposures, and longitudinal clinical trajectories before synthesizing unified clinical recommendations.

These multimodal representations substantially improve diagnosis, prognostic prediction, biomarker discovery, therapeutic optimization, disease monitoring, and personalized oncology throughout the cancer care continuum.[15]

8. Digital Health and Autonomous Monitoring

Digital health technologies including wearable biosensors, mobile health applications, remote physiological monitoring, smart medical devices, patient-reported outcomes, and Internet of Medical Things (IoMT) platforms continuously generate longitudinal physiological information throughout cancer care. Agentic foundation models integrate these digital biomarkers with laboratory investigations, molecular biology, radiological imaging, digital pathology, medication adherence, and electronic health records to enable autonomous longitudinal patient monitoring.[16]

Dedicated monitoring agents continuously evaluate treatment response, physiological deterioration, toxicity development, symptom progression, functional status, cardiovascular physiology, metabolic health, sleep quality, physical activity, medication adherence, and quality-of-life indicators. Intelligent alert systems prioritize clinically significant events while coordinating multidisciplinary communication and recommending timely clinical intervention under physician supervision.

Digital health therefore extends autonomous clinical intelligence beyond hospitals into continuous patient-centered precision oncology.[17]

9. Digital Twins and Coordinated Clinical Intelligence

One of the greatest strengths of agentic foundation models is their ability to coordinate digital twins, multimodal biomedical intelligence, laboratory biomarkers, biomedical literature, clinical guidelines, electronic health records, digital biomarkers, and longitudinal patient trajectories into continuously evolving computational ecosystems. Rather than analyzing individual biomedical modalities independently, coordinated autonomous agents generate comprehensive patient-specific representations capable of supporting diagnosis, prognostic prediction, biomarker discovery, therapeutic optimization, adaptive disease monitoring, recurrence prediction, survivorship management, multidisciplinary communication, and precision clinical decision-making. Human clinicians remain responsible for validating computational recommendations, interpreting uncertainty, communicating with patients, and making final treatment decisions, thereby ensuring trustworthy, explainable, and patient-centered implementation of autonomous clinical intelligence throughout the cancer care continuum.[18][19][20]

10. Digital Twins and Autonomous Patient Simulation

Digital twin technology represents one of the most transformative applications of agentic foundation models by creating continuously evolving virtual representations of individual cancer patients synchronized with their biological counterparts. Foundation AI models integrate serial radiological imaging, digital pathology, genomics, transcriptomics, proteomics, metabolomics, epigenomics, spatial biology, laboratory biomarkers, circulating tumor DNA, wearable physiological monitoring, medication history, patient-reported outcomes, environmental exposures, and longitudinal clinical information into adaptive computational patient models capable of simulating disease progression, therapeutic response, treatment-related toxicity, recurrence, metastatic dissemination, and survival.[21]

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Unlike conventional predictive models, digital twins continuously update their computational representations as new biomedical information becomes available. Agentic reasoning systems interact with these virtual patients to evaluate multiple therapeutic strategies, optimize treatment sequencing, anticipate mechanisms of therapeutic resistance, personalize supportive care, estimate long-term clinical outcomes, and recommend adaptive interventions according to evolving patient biology. Autonomous simulation enables rapid evaluation of alternative clinical scenarios while maintaining continuous clinician oversight.

By combining multimodal biomedical intelligence with predictive simulation, digital twins transform computational oncology from retrospective analysis toward proactive, adaptive, and continuously personalized precision medicine.

11. Intelligent Autonomous Clinical Decision Support

Agentic foundation models provide the computational infrastructure for next-generation clinical decision-support systems capable of integrating heterogeneous biomedical information into comprehensive patient-centered recommendations while coordinating complex clinical workflows under physician supervision. Rather than independently interpreting radiological imaging, digital pathology, molecular diagnostics, laboratory investigations, wearable physiological monitoring, medication history, physician documentation, patient-reported outcomes, and evidence-based clinical guidelines, autonomous clinical intelligence systems synthesize diverse biomedical information into unified computational representations supporting multidisciplinary oncology practice.[22]

Specialized diagnostic, therapeutic, pharmacological, pathology, radiology, molecular, and evidence-synthesis agents collaborate to generate individualized diagnostic summaries, biomarker analyses, molecular interpretations, digital twin simulations, therapeutic recommendations, toxicity estimates, recurrence probabilities, disease progression forecasts, survival predictions, and longitudinal treatment response assessments. These recommendations are presented through interactive clinical dashboards that facilitate collaboration among oncologists, radiologists, pathologists, surgeons, radiation oncologists, molecular biologists, pharmacists, nurses, genetic counselors, biomedical engineers, computational scientists, and healthcare administrators.

Human clinicians remain responsible for validating recommendations, interpreting uncertainty, integrating patient preferences, and making final clinical decisions, thereby ensuring trustworthy implementation of autonomous clinical intelligence.

12. Continuous Learning and Adaptive Agentic Intelligence

A defining characteristic of agentic foundation models is the ability to continuously evolve as new biomedical information becomes available while autonomously refining clinical reasoning. Artificial intelligence incorporates serial imaging examinations, computational pathology, circulating tumor DNA, laboratory biomarkers, wearable physiological monitoring, medication adherence, patient-reported outcomes, biomedical literature, pharmacological evidence, evolving clinical guidelines, and real-world treatment outcomes into adaptive computational frameworks capable of continuously improving predictive performance throughout the patient's clinical journey.[23]

Continual learning algorithms enable incremental refinement of computational knowledge without catastrophic forgetting, while reinforcement learning optimizes diagnostic reasoning, therapeutic planning, workflow coordination, toxicity management, and supportive care through iterative evaluation of longitudinal patient outcomes. Agentic systems further integrate clinician feedback, multidisciplinary tumor board recommendations, and validated treatment decisions into continuous model improvement.

This adaptive computational paradigm transforms oncology into a continuously learning healthcare ecosystem capable of rapidly translating scientific discoveries into personalized clinical care.

13. Federated Agentic Oncology Networks

Development of highly generalizable agentic foundation models requires access to diverse biomedical datasets representing multiple healthcare systems, imaging platforms, pathology

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laboratories, molecular technologies, wearable ecosystems, treatment protocols, and patient populations. Federated learning enables collaborative development of autonomous clinical intelligence while preserving patient privacy and institutional governance through decentralized computational training.[24]

Participating healthcare institutions independently train local multimodal foundation models using radiological imaging, digital pathology, genomics, transcriptomics, proteomics, laboratory investigations, wearable monitoring, liquid biopsy, electronic health records, and longitudinal clinical records while securely exchanging encrypted model parameters rather than identifiable patient information. Federated orchestration enables autonomous coordination among distributed computational agents while maintaining institutional autonomy and regulatory compliance.

These collaborative computational ecosystems establish international oncology intelligence networks capable of accelerating scientific discovery, improving external validity, reducing algorithmic bias, promoting equitable precision medicine, and supporting global cancer research while maintaining responsible biomedical data stewardship.

14. Explainability, Validation, and Ethical Governance

Successful implementation of agentic foundation models in oncology requires transparent, interpretable, reproducible, and rigorously validated computational systems capable of supporting clinician confidence, patient trust, and regulatory approval. Explainable artificial intelligence (XAI) enables clinicians to understand autonomous computational reasoning through attention visualization, saliency maps, SHAP (Shapley Additive Explanations), feature attribution analysis, uncertainty estimation, confidence calibration, multimodal attention mapping, workflow tracing, and counterfactual explanations identifying the imaging, molecular, pathological, physiological, and clinical variables responsible for predictive outputs.[25]

Clinical deployment additionally requires standardized multimodal datasets, interoperable computational infrastructure, prospective multicenter validation, external benchmarking, cybersecurity safeguards, continuous monitoring for algorithmic bias, transparent reporting standards, human oversight mechanisms, and compliance with evolving international regulatory frameworks governing AI-enabled healthcare technologies.

Responsible implementation further depends upon patient privacy, informed consent, transparency, accountability, fairness, equitable access, responsible data governance, continuous post-deployment surveillance, clinician education, and multidisciplinary oversight to ensure trustworthy integration of autonomous clinical intelligence into routine oncology practice.

15. Future Perspectives

Future agentic oncology ecosystems will increasingly integrate multimodal foundation models, multimodal large language models, graph neural networks, reinforcement learning, federated learning, digital twins, spatial multi-omics, single-cell sequencing, liquid biopsy, quantum computing, Internet of Medical Things (IoMT), robotics, autonomous laboratory platforms, cloud-native healthcare infrastructure, biomedical knowledge graphs, and explainable reasoning engines into unified precision oncology platforms.[26]

These next-generation computational ecosystems will continuously integrate molecular biology, radiological imaging, digital pathology, laboratory medicine, wearable physiological monitoring, environmental exposures, electronic health records, biomedical literature, pharmacological databases, and real-world clinical outcomes while autonomously coordinating diagnostic workflows, adaptive clinical trials, personalized therapeutics, survivorship management, multidisciplinary communication, patient education, and continuous evidence synthesis.

Future autonomous clinical intelligence will increasingly function as an intelligent collaborative partner that augments multidisciplinary oncology teams while preserving human empathy, ethical reasoning, contextual understanding, and patient-centered communication.

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16. Discussion

Agentic foundation models represent one of the most significant paradigm shifts in computational oncology by integrating autonomous reasoning, multimodal biomedical intelligence, digital twins, molecular biology, radiological imaging, digital pathology, laboratory biomarkers, wearable technologies, biomedical literature, and longitudinal clinical intelligence into unified computational ecosystems capable of supporting comprehensive personalized cancer care. Unlike conventional artificial intelligence systems that perform isolated prediction tasks, agentic models coordinate complex clinical workflows, continuously synthesize evolving biomedical knowledge, and adapt recommendations according to dynamic patient trajectories while maintaining meaningful clinician oversight.[27]

Applications spanning computational pathology, radiogenomics, biomarker discovery, precision immunotherapy, adaptive therapeutics, intelligent clinical trials, digital twins, remote patient monitoring, federated collaboration, digital health, survivorship management, autonomous workflow coordination, and explainable clinical decision support demonstrate the extraordinary potential of agentic foundation models to redefine future oncology. Nevertheless, successful implementation requires continued advances in multimodal data harmonization, explainable artificial intelligence, interoperability, computational infrastructure, cybersecurity, regulatory science, ethical governance, clinician education, and sustained multidisciplinary collaboration.

As biomedical knowledge and healthcare data continue to expand exponentially, autonomous clinical intelligence is expected to become a foundational computational infrastructure supporting precision oncology worldwide.

17. Conclusion

Agentic foundation models are transforming precision oncology by integrating autonomous reasoning, multimodal clinical intelligence, radiological imaging, digital pathology, multi-omics, laboratory biomarkers, wearable technologies, electronic health records, digital biomarkers, digital twins, and longitudinal clinical intelligence into unified computational ecosystems capable of supporting accurate diagnosis, biomarker discovery, prognostic prediction, therapeutic optimization, adaptive disease monitoring, and continuously personalized cancer care throughout the cancer care continuum.[28]

Advances in transformer architectures, multimodal learning, graph neural networks, self-supervised learning, federated learning, reinforcement learning, multimodal large language models, explainable artificial intelligence, digital twins, agentic AI, and generative artificial intelligence are expected to further strengthen intelligent oncology ecosystems, enabling increasingly accurate molecular characterization, transparent clinical reasoning, adaptive therapeutics, continuous disease surveillance, and predictive precision medicine.[29]

Although important scientific, technical, ethical, regulatory, and implementation challenges remain, sustained collaboration among oncologists, radiologists, pathologists, molecular biologists, biomedical engineers, computer scientists, nurses, healthcare organizations, policymakers, industry partners, patients, and regulatory agencies will accelerate the responsible implementation of agentic foundation models. These innovations have the potential to improve patient outcomes, enhance healthcare efficiency, reduce disparities in cancer care, accelerate translational research, and establish a new era of intelligent, adaptive, trustworthy, autonomous, and continuously learning precision oncology worldwide.[30]

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