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NEXT-GENERATION INTELLIGENT ONCOLOGY: CONVERGING AGENTIC AI, FOUNDATION MODELS, AND PRECISION MEDICINE FOR PERSONALIZED CANCER CARE

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Abstract: Next-generation intelligent oncology is emerging as a transformative paradigm in precision medicine through the convergence of agentic artificial intelligence (AI), foundation models, multimodal biomedical intelligence, and adaptive clinical decision support. Conventional precision oncology has significantly improved diagnosis and targeted therapy through molecular characterization; however, fragmented biomedical data, limited interoperability, static predictive models, and increasing clinical complexity continue to challenge personalized cancer management. Recent advances in foundation AI models, multimodal transformer architectures, graph neural networks, self-supervised learning, reinforcement learning, agentic AI, and generative artificial intelligence have enabled seamless 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. Agentic AI extends these capabilities through autonomous planning, workflow orchestration, adaptive reasoning, evidence synthesis, and intelligent collaboration with multidisciplinary oncology teams under continuous human supervision. These intelligent systems support precision diagnosis, biomarker discovery, prognostic prediction, therapeutic optimization, digital twin simulation, adaptive clinical trials, survivorship management, and evidence-based personalized cancer care. Emerging technologies including multimodal large language models, federated learning, retrieval-augmented generation, explainable artificial intelligence, cancer knowledge graphs, cloud-native healthcare platforms, robotics, and digital health ecosystems further strengthen intelligent oncology by enabling collaborative, privacy-preserving, transparent, and continuously adaptive biomedical intelligence. Despite remarkable technological progress, important scientific, technical, ethical, and regulatory challenges remain regarding multimodal data harmonization, computational scalability, interoperability, cybersecurity, clinical validation, governance, and equitable implementation. This review provides a comprehensive overview of next-generation intelligent oncology, emphasizing convergence of agentic AI, foundation models, and precision medicine for personalized cancer care.[1]

Keywords: *Agentic AI, Foundation models, Precision oncology, Intelligent oncology, Personalized medicine, Digital twins, Computational oncology, Clinical decision support, Artificial intelligence, Multimodal learning.*

1. Introduction

Cancer is a biologically dynamic disease characterized by continuous genomic evolution, epigenetic remodeling, immune adaptation, metabolic reprogramming, angiogenesis, stromal remodeling, therapeutic resistance, and intricate interactions among malignant cells, immune populations, extracellular matrix, vascular structures, and host physiology. These interconnected biological processes evolve throughout diagnosis, treatment, recurrence, metastasis, and survivorship, requiring computational systems capable of continuously integrating 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, pharmacological databases, and patient-reported outcomes. Although each modality contributes valuable biological insight, isolated interpretation frequently limits comprehensive understanding of evolving cancer biology and individualized therapeutic decision-making.[3]

The convergence of agentic AI, foundation models, and precision medicine establishes a transformative computational framework capable of continuously integrating biomedical knowledge, supporting adaptive clinical reasoning, and enabling intelligent personalized oncology throughout the cancer care continuum.

2. Evolution of Intelligent Oncology

Artificial intelligence in oncology has evolved from narrow computer-aided diagnostic systems toward intelligent computational ecosystems capable of generalized reasoning, multimodal integration, and autonomous workflow coordination. Early machine learning algorithms primarily focused on isolated prediction tasks such as lesion classification, pathology interpretation, survival estimation, or biomarker identification. Although clinically valuable, these systems demonstrated limited 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 multimodal self-supervised learning, while agentic AI extends these capabilities through autonomous planning, adaptive reasoning, workflow orchestration, and continuous collaboration with clinicians, thereby establishing intelligent oncology ecosystems supporting personalized medicine.[5]

3. Principles of Agentic Foundation Models

Foundation AI models differ fundamentally from conventional predictive algorithms because they acquire generalized biomedical representations from massive multimodal datasets before specialization for individual oncology applications. Agentic AI extends these representations through autonomous planning, long-term reasoning, adaptive execution, and coordinated decision-making under continuous human supervision.[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 unified computational embedding spaces.

Graph neural networks further characterize interactions among genes, proteins, signaling pathways, metabolites, immune populations, imaging phenotypes, tissue architecture, therapeutic targets, physiological variables, environmental exposures, and clinical outcomes, enabling systems-level computational reasoning supporting intelligent precision oncology.[7]

4. Computational Architecture

Modern intelligent oncology platforms consist of interconnected computational layers responsible for biomedical data acquisition, preprocessing, multimodal representation learning, autonomous reasoning, workflow orchestration, graph inference, predictive analytics, digital twin simulation, 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, pharmacological databases, clinical guidelines, and electronic

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health records. Advanced preprocessing pipelines normalize imaging studies, harmonize molecular datasets, encode biomedical 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 while agentic reasoning modules coordinate adaptive clinical workflows throughout precision oncology.[9]

5. Agentic AI for Precision Diagnosis

Precision diagnosis represents one of the most important applications of next-generation intelligent oncology. Agentic AI integrates radiological imaging, digital pathology, laboratory biomarkers, molecular diagnostics, physician documentation, biomedical literature, and clinical guidelines into coordinated diagnostic reasoning workflows supporting multidisciplinary oncology practice.[10]

Specialized diagnostic agents automatically identify suspicious lesions, quantify tumor burden, characterize imaging phenotypes, analyze histopathological architecture, interpret genomic alterations, evaluate laboratory biomarkers, retrieve scientific evidence, and synthesize comprehensive diagnostic summaries. Human clinicians subsequently validate computational recommendations while incorporating contextual clinical information, patient preferences, and multidisciplinary expertise.

These coordinated computational capabilities substantially improve diagnostic accuracy, workflow efficiency, biomarker interpretation, and personalized oncology.[11]

6. Intelligent Therapeutic Planning

Personalized therapeutic planning requires simultaneous evaluation of molecular biomarkers, imaging phenotypes, histopathological findings, laboratory investigations, treatment history, physiological monitoring, pharmacological evidence, patient preferences, and evolving biomedical knowledge. Agentic foundation models synthesize these heterogeneous 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, retrieve evidence from clinical trials, analyze drug interactions, optimize treatment sequencing, and recommend individualized supportive care strategies. These coordinated recommendations are subsequently reviewed by multidisciplinary oncology teams before implementation.

This collaborative computational paradigm substantially improves evidence-based precision therapeutics while preserving clinician responsibility and patient-centered decision-making.[13]

7. Multimodal Biomedical Intelligence

Comprehensive intelligent 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.[15]

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8. Digital Health and Continuous Clinical Intelligence

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, environmental exposures, and electronic health records to enable intelligent 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 intelligent oncology beyond hospitals into continuous patient-centered precision medicine.[17]

9. Converged Intelligent Oncology Ecosystems

One of the greatest strengths of next-generation intelligent oncology is the convergence of agentic AI, foundation models, radiology, pathology, multi-omics, laboratory biomarkers, biomedical literature, pharmacological knowledge, electronic health records, digital biomarkers, patient-reported outcomes, and longitudinal clinical trajectories into unified computational ecosystems. Rather than analyzing individual biomedical modalities independently, coordinated autonomous reasoning systems generate comprehensive patient-specific representations capable of supporting diagnosis, biomarker discovery, prognostic prediction, 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 intelligent oncology throughout the cancer care continuum.[18][19][20]

10. Digital Twins and Intelligent Virtual Patient Ecosystems

Digital twin technology represents one of the most transformative applications of next-generation intelligent oncology 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]

Unlike conventional predictive models, intelligent digital twins continuously update their computational representations as new biomedical information becomes available. Integration of multimodal molecular biology with predictive simulation enables virtual patients to evaluate multiple therapeutic strategies before implementation, optimize treatment sequencing, anticipate mechanisms of therapeutic resistance, personalize supportive care, estimate long-term clinical outcomes, and support adaptive treatment planning according to evolving patient biology.

When coordinated by agentic AI, digital twins become active computational partners capable of continuously monitoring patient trajectories, identifying clinically meaningful deviations, recommending evidence-based interventions, and supporting multidisciplinary oncology teams with predictive intelligence throughout the cancer care continuum.

11. Intelligent 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, biomedical literature, 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, survivorship, 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. Interactive clinical dashboards facilitate communication among oncologists, radiologists, pathologists, surgeons, radiation oncologists, molecular biologists, pharmacists, nurses, genetic counselors, biomedical engineers, computational scientists, and healthcare administrators.

Clinicians remain responsible for validating recommendations, interpreting uncertainty, integrating patient preferences, balancing ethical considerations, and making final clinical decisions, thereby ensuring trustworthy implementation of intelligent oncology.

12. Continuous Learning and Adaptive Oncology Intelligence

A defining characteristic of next-generation intelligent oncology 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, survivorship care, and supportive interventions through iterative evaluation of longitudinal patient outcomes. Agentic systems further integrate clinician feedback, multidisciplinary tumor board recommendations, and emerging biomedical discoveries 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 Intelligent Oncology Networks

Development of highly generalizable intelligent oncology systems requires access to diverse biomedical datasets representing multiple healthcare systems, imaging platforms, pathology laboratories, molecular technologies, wearable ecosystems, treatment protocols, and patient populations. Federated learning enables collaborative development of agentic foundation models while preserving patient privacy and institutional governance through decentralized computational training.[24]

Participating healthcare institutions independently train local multimodal models using radiological imaging, digital pathology, genomics, transcriptomics, proteomics, metabolomics, laboratory investigations, wearable monitoring, liquid biopsy, electronic health records, biomedical literature, and longitudinal clinical records while securely exchanging encrypted model parameters rather than identifiable patient information. Federated orchestration enables distributed intelligence to improve global model performance while maintaining institutional autonomy and regulatory compliance.

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

14. Explainability, Validation, and Ethical Governance

Successful implementation of next-generation intelligent 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 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, pharmacological, 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 intelligent oncology into routine clinical practice.

15. Future Perspectives

Future intelligent oncology ecosystems will increasingly integrate multimodal foundation models, multimodal large language models, agentic artificial intelligence, 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, retrieval-augmented generation, and explainable reasoning systems 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, global clinical guidelines, and real-world clinical outcomes while autonomously coordinating diagnostics, biomarker discovery, adaptive clinical trials, personalized therapeutics, survivorship management, multidisciplinary communication, patient education, and continuous evidence synthesis.

Such converged intelligent ecosystems are expected to transform oncology from fragmented disease management toward predictive, preventive, adaptive, continuously learning, and precision-guided cancer medicine.

16. Discussion

Next-generation intelligent oncology represents one of the most significant paradigm shifts in computational cancer medicine by integrating agentic AI, foundation models, digital twins, radiology, pathology, multi-omics, laboratory biomarkers, biomedical literature, digital biomarkers, 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, converged intelligent ecosystems continuously synthesize heterogeneous molecular, imaging, pathological, physiological, pharmacological, and clinical information while autonomously coordinating multidisciplinary workflows under meaningful human supervision.[27]

Applications spanning computational pathology, radiogenomics, biomarker discovery, digital twins, precision immunotherapy, adaptive therapeutics, intelligent clinical trials, remote patient monitoring, federated collaboration, digital health, survivorship management, explainable clinical decision support, and translational research demonstrate the extraordinary potential of converged computational intelligence 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, intelligent oncology ecosystems are expected to become one of the foundational computational infrastructures supporting precision oncology worldwide.

17. Conclusion

Next-generation intelligent oncology is transforming personalized cancer care by integrating agentic AI, foundation models, radiological imaging, digital pathology, multi-omics, laboratory biomarkers, biomedical literature, 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 precision clinical decision-making throughout the cancer care continuum.[28]

Advances in multimodal transformer architectures, graph neural networks, self-supervised learning, federated learning, reinforcement learning, multimodal large language models, explainable artificial intelligence, digital twins, agentic AI, retrieval-augmented generation, and generative artificial intelligence are expected to further strengthen intelligent oncology ecosystems, enabling increasingly accurate molecular characterization, predictive clinical reasoning, adaptive therapeutics, continuous disease surveillance, and personalized 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 next-generation intelligent oncology. These innovations have the potential to improve patient outcomes, enhance healthcare efficiency, reduce disparities in cancer care, accelerate translational research, facilitate precision therapeutics, and establish a new era of intelligent, adaptive, trustworthy, and continuously learning precision oncology worldwide.[30]

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