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TOWARDS GENERALIST ARTIFICIAL INTELLIGENCE IN ONCOLOGY: FOUNDATION MODELS FOR INTEGRATED CANCER DIAGNOSIS AND PERSONALIZED CARE

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Abstract: The rapid evolution of artificial intelligence (AI) has accelerated the transition from task-specific algorithms toward generalist foundation models capable of performing diverse clinical, molecular, and imaging tasks using unified computational intelligence. In oncology, these next-generation systems have the potential to transform cancer diagnosis and personalized care by integrating heterogeneous biomedical information into continuously learning computational ecosystems. Conventional oncology frequently depends on fragmented interpretation of radiological imaging, digital pathology, molecular diagnostics, laboratory investigations, and clinical information, limiting comprehensive understanding of the dynamic biological complexity of cancer. Recent advances in foundation AI models, multimodal transformer architectures, graph neural networks, self-supervised learning, and generative artificial intelligence have enabled generalized biomedical representation learning across radiological imaging, digital pathology, genomics, transcriptomics, proteomics, metabolomics, epigenomics, spatial biology, laboratory biomarkers, circulating tumor DNA, wearable physiological monitoring, electronic health records, and longitudinal clinical outcomes. These intelligent computational systems support early cancer detection, molecular characterization, biomarker discovery, prognostic prediction, therapeutic optimization, immunotherapy selection, digital twin simulation, adaptive disease monitoring, and intelligent clinical decision support. Emerging technologies including multimodal large language models, federated learning, reinforcement learning, retrieval-augmented generation, explainable artificial intelligence, and agentic AI further strengthen generalist oncology intelligence by enabling collaborative, privacy-preserving, transparent, and continuously adaptive biomedical reasoning. Despite remarkable technological advances, important scientific, technical, ethical, and regulatory challenges remain regarding multimodal data harmonization, computational scalability, interpretability, interoperability, cybersecurity, clinical validation, and equitable implementation. This review provides a comprehensive overview of generalist artificial intelligence in oncology, emphasizing foundation models for integrated cancer diagnosis and personalized patient care.[1]

Keywords: *Generalist artificial intelligence, Foundation models, Precision oncology, Computational oncology, Multimodal learning, Personalized medicine, Digital pathology, Radiomics, Clinical intelligence, Clinical decision support.*

1. Introduction

Cancer is a biologically dynamic disease characterized by continuous genomic evolution, epigenetic remodeling, immune adaptation, metabolic reprogramming, angiogenesis, tissue remodeling, and intricate interactions among malignant cells, stromal components, immune populations, and host physiology. These interconnected biological processes evolve throughout diagnosis, treatment, recurrence, metastasis, and survivorship, making precision oncology increasingly dependent upon computational systems capable of integrating heterogeneous biomedical information across multiple biological scales.[2]

Modern oncology routinely generates enormous quantities of biomedical information through radiological imaging, digital pathology, genomic sequencing, transcriptomics, proteomics, metabolomics, epigenomics, spatial biology,

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laboratory investigations, circulating tumor DNA, wearable physiological monitoring, physician documentation, electronic health records, and patient-reported outcomes. Although each modality contributes valuable biological insight, isolated interpretation frequently overlooks systems-level relationships governing disease progression, therapeutic response, resistance mechanisms, and long-term clinical outcomes.[3]

Artificial intelligence has emerged as a transformative computational technology capable of integrating these heterogeneous biomedical datasets into unified patient-centered representations. Foundation AI models extend these capabilities through generalized multimodal learning that enables knowledge transfer across diverse oncology applications while continuously adapting to evolving biomedical evidence.

The emergence of generalist artificial intelligence therefore represents a transformative paradigm shift toward integrated cancer diagnosis and personalized precision oncology.[4]

2. Evolution from Task-Specific AI to Generalist Foundation Models

Artificial intelligence in oncology has evolved from conventional statistical analyses toward intelligent biomedical ecosystems capable of continuously learning from multimodal healthcare data. Early machine learning approaches primarily relied upon handcrafted feature engineering and task-specific predictive algorithms developed for isolated diagnostic or prognostic applications. Although these systems demonstrated clinical value, they remained constrained by fragmented biomedical information, limited adaptability, and narrow generalizability.[5]

Deep learning substantially advanced computational oncology through automated representation learning from radiological imaging, digital pathology, genomic sequencing, and electronic health records. Transformer architectures subsequently revolutionized biomedical artificial intelligence by enabling generalized contextual learning across heterogeneous biomedical modalities.

Foundation AI models now acquire transferable biomedical knowledge through large-scale self-supervised pretraining, allowing a single computational architecture to perform diverse oncology tasks including diagnosis, prognosis, biomarker discovery, therapeutic prediction, disease monitoring, radiomics, pathomics, genomics, and clinical reasoning. This transition marks the emergence of generalist artificial intelligence in oncology.[6]

3. Principles of Generalist Foundation Models

Generalist foundation AI models differ fundamentally from conventional artificial intelligence because they acquire generalized biomedical representations from massive multimodal datasets before specialization for individual oncology applications. Rather than learning isolated predictive tasks, these models develop transferable computational knowledge applicable across diagnosis, prognosis, molecular characterization, biomarker discovery, therapeutic optimization, disease monitoring, computational pathology, radiomics, immunotherapy, and clinical decision support.[7]

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, laboratory biomarkers, wearable physiological monitoring, physician documentation, patient-reported outcomes, and longitudinal clinical trajectories within unified computational embedding spaces.

Graph neural networks further characterize interactions among genes, proteins, signaling pathways, immune populations, imaging phenotypes, tissue architecture, therapeutic targets, physiological variables, and clinical outcomes, thereby enabling systems-level computational reasoning supporting precision oncology.[8]

4. Computational Architecture

Modern generalist oncology platforms consist of interconnected computational layers responsible for biomedical data acquisition, preprocessing, representation learning, multimodal fusion, adaptive learning, predictive analytics, digital twin

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simulation, and intelligent clinical decision support.[9]

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, and electronic health records. Advanced preprocessing pipelines normalize imaging studies, harmonize molecular datasets, encode clinical narratives using natural language processing, and synchronize temporal patient information.

Foundation AI models subsequently generate generalized multimodal embeddings representing molecular biology, tissue architecture, imaging phenotypes, physiological function, and longitudinal clinical trajectories. These unified computational representations support diagnosis, biomarker discovery, prognostic prediction, therapeutic optimization, adaptive learning, and integrated cancer care.[10]

5. Integrated Cancer Diagnosis

One of the defining capabilities of generalist artificial intelligence is integrated cancer diagnosis through simultaneous analysis of multiple biomedical modalities. Foundation AI models combine radiological imaging, digital pathology, molecular diagnostics, laboratory biomarkers, genomic sequencing, liquid biopsy, and electronic health records into unified computational representations capable of identifying subtle biological abnormalities associated with early tumorigenesis and disease progression.[11]

Deep learning algorithms automatically detect radiological abnormalities across mammography, computed tomography, magnetic resonance imaging, ultrasound, positron emission tomography, and endoscopic imaging while minimizing observer variability. Simultaneously, computational pathology identifies microscopic tissue alterations, immune infiltration, stromal remodeling, angiogenesis, fibrosis, and cellular heterogeneity that complement imaging findings.

Integration of imaging, pathology, and molecular intelligence substantially improves diagnostic accuracy while enabling comprehensive biological characterization of individual tumors.[12]

6. Generalist Molecular Intelligence

Comprehensive molecular characterization represents one of the greatest strengths of generalist foundation AI models. Artificial intelligence integrates genomics, transcriptomics, proteomics, metabolomics, epigenomics, immunomics, microbiomics, spatial biology, and single-cell sequencing into generalized molecular representations capable of characterizing evolving tumor biology across multiple organizational scales.[13]

Transformer architectures identify latent biological relationships among genes, proteins, signaling pathways, metabolites, immune responses, and therapeutic targets, while graph neural networks model complex biological interaction networks supporting systems-level computational reasoning.

These generalized molecular representations enable discovery of molecular subtypes, therapeutic biomarkers, resistance mechanisms, prognostic signatures, and novel drug targets while substantially improving individualized precision medicine.[14]

7. Multimodal Clinical Intelligence

Clinical intelligence represents the integration of structured and unstructured clinical information into continuously evolving computational representations supporting multidisciplinary oncology practice. Electronic health records, laboratory investigations, medication history, physician documentation, patient-reported outcomes, wearable physiological monitoring, and longitudinal clinical trajectories collectively provide comprehensive patient-level information extending beyond molecular diagnostics.[15]

Foundation AI models integrate these diverse clinical datasets with imaging and molecular biology using natural language processing, temporal transformers, and multimodal reasoning architectures. These unified computational representations enable adaptive prediction of disease progression, therapeutic response,

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recurrence, hospitalization, survivorship outcomes, and overall survival while supporting evidence-based clinical decision-making throughout diagnosis, treatment, follow-up, and survivorship.[16]

8. Multimodal Learning for Personalized Care

The defining capability of generalist artificial intelligence is multimodal learning, whereby radiological imaging, digital pathology, multi-omics, laboratory biomarkers, wearable physiological monitoring, physician documentation, environmental exposures, and longitudinal clinical trajectories are integrated into unified patient-specific computational representations. Artificial intelligence employs multimodal transformers, graph neural networks, biological knowledge graphs, and cross-modal attention mechanisms to identify latent biological relationships spanning molecular, cellular, tissue, organ, physiological, and clinical scales.[17]

These comprehensive multimodal representations substantially improve diagnostic classification, biomarker discovery, prognostic prediction, therapeutic optimization, digital twin simulation, and adaptive precision oncology while enabling systems-level computational understanding of cancer biology.[18]

9. Personalized Therapeutic Decision-Making

One of the most clinically important applications of generalist artificial intelligence is individualized therapeutic optimization through comprehensive integration of molecular biology, imaging phenotypes, histopathological characteristics, laboratory biomarkers, wearable physiological monitoring, medication history, and longitudinal clinical trajectories. Foundation AI models continuously predict responsiveness to chemotherapy, targeted therapy, endocrine therapy, immunotherapy, radiation therapy, surgery, and multimodal treatment combinations while adapting therapeutic recommendations according to evolving patient biology, treatment response, toxicity profiles, and real-world clinical outcomes. These adaptive computational systems establish a comprehensive framework for integrated precision oncology capable of improving patient outcomes across the entire cancer care continuum.[19][20]

10. Digital Twins and Intelligent Virtual Patient Modeling

Digital twin technology represents one of the most transformative applications of generalist artificial intelligence 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, laboratory biomarkers, circulating tumor DNA, wearable physiological monitoring, medication history, patient-reported outcomes, 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, digital twins continuously update their computational representations as new biomedical information becomes available. These intelligent virtual patients enable clinicians to evaluate multiple therapeutic strategies before implementation, optimize treatment sequencing, anticipate mechanisms of therapeutic resistance, and personalize supportive care according to evolving patient biology.

By combining multimodal biomedical intelligence with predictive simulation, digital twins transform computational oncology from retrospective analysis toward proactive precision medicine supported by continuously adaptive virtual patient ecosystems.

11. Intelligent Clinical Decision Support

Generalist foundation AI models provide the computational infrastructure for next-generation clinical decision-support systems capable of integrating heterogeneous biomedical information into comprehensive patient-centered recommendations. Rather than interpreting radiological imaging, digital pathology, molecular diagnostics, laboratory investigations, wearable physiological monitoring, medication history, physician documentation, patient-reported

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outcomes, and evidence-based clinical guidelines independently, these models synthesize diverse biomedical information into unified computational representations supporting multidisciplinary oncology practice.[22]

Interactive clinical dashboards generate individualized diagnostic summaries, multimodal biomarker analyses, digital twin simulations, therapeutic recommendations, toxicity estimates, recurrence probabilities, disease progression forecasts, and survival predictions while facilitating collaboration among oncologists, radiologists, pathologists, surgeons, radiation oncologists, molecular biologists, pharmacists, nurses, genetic counselors, and computational scientists.

These intelligent systems improve workflow efficiency, strengthen multidisciplinary communication, reduce fragmentation of biomedical information, and promote evidence-based personalized cancer management throughout the cancer care continuum.

12. Continuous Learning and Adaptive Generalist Intelligence

A defining characteristic of generalist artificial intelligence is its ability to continuously evolve as new biomedical information becomes available. Artificial intelligence incorporates serial imaging examinations, computational pathology, circulating tumor DNA, laboratory biomarkers, wearable physiological monitoring, medication adherence, patient-reported outcomes, and real-world clinical evidence into adaptive computational frameworks capable of continuously refining predictive accuracy throughout the patient's clinical journey.[23]

Continual learning algorithms enable incremental refinement of computational knowledge without catastrophic forgetting of previously acquired information, while reinforcement learning optimizes therapeutic recommendations through iterative evaluation of treatment outcomes. Agentic AI systems further coordinate evidence retrieval, diagnostic reasoning, workflow automation, treatment planning, and longitudinal disease surveillance with minimal manual intervention.

This adaptive computational paradigm transforms oncology into a continuously learning healthcare ecosystem capable of supporting real-time personalized precision medicine

13. Federated Generalist Foundation Model Networks

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

Participating healthcare institutions independently train local models using radiological imaging, digital pathology, genomics, transcriptomics, laboratory investigations, wearable monitoring, liquid biopsy, electronic health records, and longitudinal clinical records while securely exchanging encrypted model parameters rather than identifiable patient information. This collaborative learning strategy substantially improves algorithm robustness, fairness, external validity, and generalizability across diverse healthcare environments.

Federated generalist AI ecosystems therefore establish international computational oncology networks capable of accelerating scientific discovery, improving equitable access to precision medicine, and supporting global cancer research while maintaining responsible biomedical data stewardship.

14. Explainability, Validation, and Ethical Governance

Successful implementation of generalist artificial intelligence 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

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estimation, 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, and compliance with evolving international regulatory frameworks governing AI-enabled healthcare technologies.

Responsible implementation further depends upon protection of patient privacy, informed consent, transparency, accountability, equitable access, responsible data governance, and continuous post-deployment surveillance to ensure trustworthy integration of generalist AI into routine oncology practice.

15. Future Perspectives

Future generalist 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, liquid biopsy, quantum computing, Internet of Medical Things (IoMT), robotics, and cloud-native healthcare infrastructure into unified precision oncology platforms.[26]

These next-generation computational ecosystems will continuously integrate molecular biology, imaging, pathology, laboratory medicine, wearable physiological monitoring, environmental exposures, electronic health records, biomedical literature, and real-world clinical outcomes while autonomously coordinating diagnostic workflows, optimizing therapeutic strategies, supporting adaptive clinical trials, generating personalized patient communication, and continuously synthesizing biomedical evidence.

Such intelligent ecosystems are expected to transform oncology from fragmented and reactive disease management toward predictive, preventive, adaptive, continuously learning, and precision-guided healthcare across the global cancer community.

16. Discussion

Generalist artificial intelligence represents one of the most significant paradigm shifts in computational oncology by integrating molecular biology, radiological imaging, digital pathology, laboratory biomarkers, digital twins, wearable technologies, and longitudinal clinical intelligence into unified computational ecosystems capable of supporting comprehensive personalized cancer care. Unlike conventional artificial intelligence systems developed for isolated predictive tasks, these intelligent frameworks simultaneously analyze molecular biology, tissue architecture, imaging phenotypes, laboratory biomarkers, physiological monitoring, environmental influences, and longitudinal clinical trajectories to generate holistic computational representations of evolving cancer biology.[27]

Applications spanning computational pathology, radiogenomics, biomarker discovery, precision immunotherapy, digital twins, adaptive therapeutics, continuous learning, federated collaboration, digital health, survivorship management, and intelligent clinical decision support demonstrate the extraordinary potential of generalist 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, and sustained multidisciplinary collaboration.

As biomedical knowledge and healthcare data continue to expand exponentially, generalist artificial intelligence is expected to become the central computational infrastructure supporting integrated precision oncology worldwide.

17. Conclusion

Generalist artificial intelligence is transforming oncology by integrating foundation models, radiological imaging, digital pathology, multi-omics, laboratory biomarkers, wearable technologies, electronic health records, digital twins, and longitudinal clinical intelligence into unified computational ecosystems capable of supporting accurate diagnosis, biomarker discovery, prognostic prediction, therapeutic

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optimization, adaptive disease monitoring, and personalized cancer care throughout the disease continuum.[28]

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

Although important scientific, technical, ethical, regulatory, and implementation challenges remain, sustained collaboration among oncologists, radiologists, pathologists, molecular biologists, biomedical engineers, computer scientists, healthcare organizations, policymakers, industry partners, and regulatory agencies will accelerate the responsible implementation of generalist artificial intelligence in oncology. 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, and continuously learning precision oncology worldwide.[30]

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