International Journal of
ADVANCED RESEARCH & INNOVATIONS

Volume 13, Issue-12
December, 2023, P02
ISSN: 2319-9253

MULTIMODAL GENERATIVE ARTIFICIAL INTELLIGENCE FOR PRECISION ONCOLOGY: FROM CANCER DIAGNOSIS TO THERAPEUTIC DISCOVERY

#1**Dr. Vishal Arora**, Professor, Department of Radiation Oncology,
Narayana Medical College, Nellore, India
Vishalarora79@gmail.com

Abstract: Multimodal generative artificial intelligence (AI) is redefining precision oncology by enabling intelligent computational systems capable of synthesizing heterogeneous biomedical information, generating clinically actionable knowledge, and supporting personalized cancer diagnosis, prognostic prediction, therapeutic optimization, and drug discovery. Unlike conventional artificial intelligence models designed for isolated prediction tasks, multimodal generative AI integrates radiological imaging, digital pathology, genomics, transcriptomics, proteomics, metabolomics, epigenomics, spatial biology, laboratory biomarkers, circulating tumor DNA, electronic health records, biomedical literature, and longitudinal clinical outcomes into unified generative foundation models capable of multimodal reasoning and knowledge generation. Recent advances in transformer architectures, self-supervised learning, graph neural networks, diffusion models, variationalautoencoders, generative adversarial networks, retrieval-augmented generation, and multimodal large language models have enabled comprehensive biomedical representation learning supporting cancer diagnosis, biomarker discovery, molecular characterization, immunotherapy selection, digital twin simulation, therapeutic optimization, adaptive disease monitoring, and intelligent clinical decision support. Emerging technologies including federated learning, explainable artificial intelligence, reinforcement learning, and agentic AI further strengthen multimodal oncology by enabling collaborative, privacy-preserving, transparent, and continuously adaptive biomedical intelligence. Despite remarkable technological progress, significant scientific, technical, ethical, and regulatory challenges remain regarding multimodal data harmonization, model interpretability, computational scalability, cybersecurity, clinical validation, and equitable implementation. This review provides a comprehensive overview of multimodal generative artificial intelligence in precision oncology, emphasizing its transformative role from cancer diagnosis to therapeutic discovery.[1]

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

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, vascular structures, 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 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, physician documentation, electronic health records, biomedical literature, 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]

Generative artificial intelligence has emerged as a transformative computational technology capable of synthesizing multimodal biomedical information, generating novel biological hypotheses, simulating molecular interactions, and supporting evidence-based clinical reasoning. Combined with foundation AI models, multimodal generative systems establish a new paradigm for intelligent precision oncology extending from diagnosis to therapeutic discovery.

2. Evolution of Generative Artificial Intelligence in Oncology

Artificial intelligence in oncology has evolved from conventional statistical analyses toward intelligent generative computational ecosystems capable of synthesizing multimodal biomedical knowledge. Early machine learning algorithms primarily relied upon handcrafted feature engineering and task-specific predictive models developed for isolated diagnostic or prognostic applications. Although these systems demonstrated clinical value, they remained constrained by fragmented biomedical information, limited adaptability, and narrow task specialization.[4]

Deep learning substantially expanded computational capabilities through automated representation learning from radiological imaging, digital pathology, genomic sequencing, and electronic health records. Subsequently, transformer architectures, variationalautoencoders, generative adversarial networks, diffusion models, and large language models revolutionized biomedical artificial intelligence by enabling high-dimensional data generation, simulation, and multimodal reasoning.

Foundation AI models now acquire transferable biomedical knowledge through self-supervised pretraining while multimodal generative AI integrates molecular biology, imaging, pathology, clinical intelligence, and biomedical literature into unified computational ecosystems supporting adaptive precision oncology.[5]

3. Principles of Multimodal Generative Foundation Models

Multimodal generative foundation models differ fundamentally from conventional artificial intelligence because they not only predict outcomes but also generate new biomedical representations, synthesize knowledge, simulate biological processes, and create clinically meaningful hypotheses across heterogeneous biomedical modalities.[6]

Foundation AI models integrate radiological imaging, digital pathology, genomics, transcriptomics, proteomics, metabolomics, laboratory biomarkers, wearable physiological monitoring, physician documentation, patient-reported outcomes, biomedical literature, and longitudinal clinical trajectories into unified multimodal embedding spaces.

Self-supervised learning enables acquisition of generalized biomedical knowledge without extensive manual annotation, while multimodal transformer architectures capture contextual relationships across heterogeneous biomedical modalities. Graph neural networks further characterize biological interactions among genes, proteins, signaling pathways, immune populations, imaging phenotypes, tissue architecture, therapeutic targets, physiological variables, and clinical outcomes.

These computational principles establish generative biomedical intelligence capable of supporting diagnosis, prognosis, biomarker discovery, therapeutic optimization, and translational oncology.[7]

4. Computational Architecture

Modern multimodal generative AI platforms consist of interconnected computational layers responsible for biomedical data acquisition, preprocessing, representation learning, multimodal fusion, generative modeling, adaptive learning, predictive analytics, digital twin simulation, and intelligent clinical decision support.[8]

The acquisition layer continuously integrates radiological imaging, digital pathology, genomic sequencing, transcriptomics, proteomics,

Paper Available at: www.ijarai.com
DOI : https://doi.org/10.65713/ijaraiv13i1202

metabolomics, epigenomics, laboratory investigations, circulating tumor DNA, physician documentation, medication history, patient-reported outcomes, biomedical literature, 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 retrieve evolving biomedical knowledge.

Foundation AI models subsequently generate generalized multimodal embeddings representing molecular biology, tissue architecture, imaging phenotypes, physiological function, biomedical knowledge, and longitudinal clinical trajectories. Generative modules further synthesize clinically relevant biomedical information while supporting adaptive precision oncology.[9]

5. Generative AI for Cancer Diagnosis

One of the most important applications of multimodal generative AI is precision cancer diagnosis through comprehensive integration of radiological imaging, digital pathology, laboratory biomarkers, circulating tumor DNA, genomic sequencing, and clinical documentation. Foundation AI models automatically generate integrated diagnostic interpretations by combining complementary biomedical evidence while identifying subtle biological abnormalities associated with malignant transformation.[10]

Generative AI can synthesize radiological findings, histopathological morphology, molecular biomarkers, and clinical history into comprehensive diagnostic reports, reducing information fragmentation while improving diagnostic consistency and multidisciplinary communication.

These generative diagnostic capabilities substantially improve early cancer detection, tumor classification, molecular characterization, and personalized clinical management.[11]

6. Molecular Intelligence and Biomarker Discovery

Comprehensive molecular characterization represents one of the greatest strengths of multimodal generative AI. Artificial intelligence integrates genomics, transcriptomics, proteomics, metabolomics, epigenomics, immunomics, microbiomics, spatial biology, and single-cell sequencing into generalized molecular representations capable of generating novel biological hypotheses regarding tumor evolution and therapeutic responsiveness.[12]

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.

Generative models further predict molecular biomarkers, therapeutic resistance mechanisms, prognostic signatures, and potential drug targets while accelerating translational oncology research and precision medicine.[13]

7. Multimodal Imaging and Digital Pathology

Radiological imaging and digital pathology provide complementary information describing cancer biology across macroscopic and microscopic organizational scales. Foundation AI models automatically extract generalized radiomic and pathomic representations from computed tomography, magnetic resonance imaging, positron emission tomography, ultrasound, and whole-slide pathology images without requiring handcrafted feature engineering.[14]

Generative artificial intelligence synthesizes imaging findings, tissue morphology, immune infiltration, angiogenesis, fibrosis, necrosis, and molecular biology into unified computational representations capable of improving diagnosis, prognostic prediction, biomarker discovery, therapeutic optimization, and longitudinal disease monitoring.

These integrated multimodal representations establish imaging intelligence as a central component of precision oncology.[15]

8. Generative Clinical Intelligence

Electronic health records provide one of the richest longitudinal sources of clinical intelligence available in oncology. Structured laboratory investigations, medication history, pathology reports, treatment timelines, physician documentation, hospitalizations, patient-reported outcomes, survivorship information, and biomedical literature collectively provide comprehensive patient-level context extending beyond molecular diagnostics.[16]

Large multimodal foundation models employ natural language processing, retrieval-augmented generation, temporal transformers, and multimodal reasoning architectures to integrate structured and unstructured clinical information with radiological imaging, digital pathology, molecular biology, laboratory biomarkers, and physiological monitoring.

These generative clinical intelligence systems produce personalized summaries, therapeutic recommendations, survivorship plans, patient education materials, multidisciplinary reports, and evidence synthesis supporting precision oncology.[17]

9. Therapeutic Discovery and Precision Medicine

One of the most transformative applications of multimodal generative artificial intelligence is therapeutic discovery through comprehensive integration of molecular biology, imaging phenotypes, histopathological characteristics, laboratory biomarkers, biomedical literature, pharmacological databases, and longitudinal clinical trajectories. Foundation AI models generate hypotheses regarding novel biomarkers, predict drug responsiveness, identify therapeutic combinations, simulate treatment resistance mechanisms, prioritize drug targets, and support adaptive clinical trial design while continuously incorporating newly generated biomedical evidence. These intelligent computational systems establish a comprehensive framework for accelerating precision therapeutics, translational oncology, and personalized cancer medicine across the entire disease continuum.[18][19][20]

10. Digital Twins and Generative Virtual Patient Modeling

Digital twin technology represents one of the most transformative applications of multimodal generative 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, generative 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 alternative therapeutic strategies, optimize treatment sequencing, anticipate mechanisms of therapeutic resistance, and personalize supportive care according to evolving patient biology. Generative AI further enables simulation of hypothetical treatment pathways and virtual clinical scenarios that support evidence-based therapeutic planning.

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

11. Intelligent Clinical Decision Support

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

Interactive clinical dashboards generate individualized diagnostic summaries, biomarker

Paper Available at: www.ijarai.com
DOI : https://doi.org/10.65713/ijaraiv13i1202

analyses, molecular interpretations, digital twin simulations, therapeutic recommendations, toxicity estimates, recurrence probabilities, disease progression forecasts, survival predictions, and evidence-based treatment rationales 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 Generative Intelligence

A defining characteristic of multimodal generative artificial intelligence is the 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, biomedical literature, clinical trial evidence, and real-world clinical data 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 retrieval-augmented generation continuously incorporates newly published biomedical evidence into clinical reasoning. Reinforcement learning further optimizes therapeutic recommendations through iterative evaluation of treatment outcomes and clinician feedback.

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

13. Federated Multimodal Generative AI Networks

Development of highly generalizable multimodal generative 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 multimodal generative models using radiological imaging, digital pathology, genomics, transcriptomics, laboratory investigations, wearable monitoring, liquid biopsy, biomedical literature, 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, transparency, and generalizability across diverse healthcare environments.

Federated generative 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 multimodal generative 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 estimation, multimodal attention mapping, evidence retrieval traceability, and counterfactual explanations identifying the imaging, molecular, pathological,

DOI : https://doi.org/10.65713/ijaraiv13i1202

physiological, and clinical variables responsible for generated recommendations.[25]
Clinical deployment additionally requires standardized multimodal datasets, interoperable computational infrastructure, prospective multicenter validation, external benchmarking, cybersecurity safeguards, continuous monitoring for hallucinations and algorithmic bias, and compliance with evolving international regulatory frameworks governing AI-enabled healthcare technologies.
Responsible implementation further depends upon patient privacy, informed consent, transparency, accountability, equitable access, responsible data governance, continuous post-deployment surveillance, and multidisciplinary oversight to ensure trustworthy integration of generative AI into routine oncology practice.

15. Future Perspectives

Future multimodal generative oncology ecosystems will increasingly integrate foundation AI 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, and cloud-native healthcare infrastructure 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, generating therapeutic hypotheses, supporting adaptive clinical trials, discovering novel biomarkers, designing candidate therapeutic strategies, and continuously synthesizing biomedical evidence.
Such intelligent generative ecosystems are expected to transform oncology from fragmented and reactive disease management toward predictive, preventive, adaptive, continuously learning, and precision-guided healthcare.

16. Discussion

Multimodal generative artificial intelligence represents one of the most significant paradigm shifts in computational oncology by integrating molecular biology, radiological imaging, digital pathology, laboratory biomarkers, biomedical literature, 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 primarily for prediction, generative AI simultaneously analyzes multimodal biomedical information, synthesizes scientific knowledge, generates clinically relevant hypotheses, proposes therapeutic strategies, and supports translational discovery while adapting to newly emerging biomedical evidence.[27]
Applications spanning computational pathology, radiogenomics, biomarker discovery, digital twins, precision immunotherapy, adaptive therapeutics, drug discovery, literature synthesis, continuous learning, federated collaboration, digital health, survivorship management, and intelligent clinical decision support demonstrate the extraordinary potential of multimodal generative AI 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, hallucination mitigation, and sustained multidisciplinary collaboration.
As biomedical knowledge and healthcare data continue to expand exponentially, multimodal generative artificial intelligence is expected to become one of the foundational computational infrastructures supporting intelligent precision oncology worldwide.

17. Conclusion

Multimodal generative artificial intelligence is transforming precision oncology by integrating foundation AI models, radiological imaging, digital pathology, multi-omics, laboratory biomarkers, wearable technologies, biomedical literature, electronic health records, digital twins, and longitudinal clinical intelligence into unified computational ecosystems capable of supporting accurate diagnosis, biomarker discovery, prognostic prediction, therapeutic optimization, adaptive disease monitoring, therapeutic discovery, and individualized clinical decision-making throughout the cancer care continuum.[28]

Advances in transformer architectures, multimodal learning, graph neural networks, self-supervised learning, federated learning, reinforcement learning, digital twins, multimodal large language models, diffusion models, agentic AI, retrieval-augmented generation, and generative artificial intelligence are expected to further strengthen intelligent oncology ecosystems, enabling increasingly accurate molecular characterization, predictive clinical intelligence, adaptive therapeutics, continuous disease surveillance, accelerated drug discovery, and continuously personalized cancer 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 multimodal generative 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, explainable, and continuously learning precision oncology worldwide.[30]

References

1. Meric-Bernstam, F. et al. (2023) ‘Enhancing Precision Oncology Through Multimodal Data Integration’, Nature Reviews Clinical Oncology, 20(4), pp. 267-283.

2. Dr. Ohmini Krishnamurthy Rajendran (Author), AI-BASED RADIOGENOMIC MODELS FOR PREDICTING IMMUNOTHERAPY RESPONSE IN SOLID TUMORS, Vol. 51 No. 4 (2023): October-December 2023, Power System Protection and Control, ISSN-1674-3415, https://pspac.info/index.php/dlbh/article/view/321, DOI: https://doi.org/10.46121/pspc.51.4.4

3. Dr. Latha Kiran Krishna Rajendran (Author), IMMUNOTHERAPY AND CELL THERAPY: DEVELOPING CAR-T CELL THERAPIES AND OTHER IMMUNE-BASED TREATMENTS FOR CANCER AND AUTOIMMUNE DISEASES, Vol. 51 No. 2 (2023): April-June 2023, Power System Protection and Control, ISSN-1674-3415, https://pspac.info/index.php/dlbh/article/view/304, DOI: https://doi.org/10.46121/pspc.51.2.7

4. Chakraborty, S. et al. (2022) ‘Multi-omics Integration in Oncology: From Data to Clinical Insights’, Cancer Cell, 40(8), pp. 805-823.

5. Dr. Ohmini Krishnamurthy Rajendran (Author), FEDERATED RADIOLOGY AI MODELS FOR MULTI-INSTITUTIONAL CANCER DIAGNOSIS WITHOUT DATA SHARING, Vol. 51 No. 4 (2023): October-December 2023, Power System Protection and Control, ISSN-1674-3415, https://pspac.info/index.php/dlbh/article/view/323, DOI: https://doi.org/10.46121/pspc.51.4.5

6. Dr. RajathaMaradiHemanth Kumar (Author), AI-Driven Liquid Biopsy Systems for Early Cancer Detection and Personalized Oncology, Vol. 51 No. 4 (2023): October–December 2023, Power System Protection and Control, ISSN: 1674-3415, https://pspac.info/index.php/dlbh/article/view/388, DOI: https://doi.org/10.46121/pspc.51.4.7

7. Joshi, A. et al. (2023) ‘Multimodal Learning for Precision Oncology: Beyond Single-modality Analysis’, npj Precision Oncology, 7(1), p. 28.

8. Huang, S.C. et al. (2020) ‘Fusion of Medical Imaging and Electronic Health Records Using Deep Learning: A Systematic Review’, npj Digital Medicine, 3(1), p. 136.

9. Dr. RajathaMaradiHemanth Kumar (Author), PAN-System Cancer Intelligence: Integrating Blood, Immune, Microbiome, and Tumor Microenvironment Data Using Foundation Models, Vol. 51 No. 4 (2023): October–December 2023, Power System Protection and Control, ISSN: 1674-3415, https://pspac.info/index.php/dlbh/article/view/389, DOI: https://doi.org/10.46121/pspc.51.4.8

10. Lambin, P. et al. (2017) 'Radiomics: Extracting More Information from Medical Images Using Advanced Feature Analysis', European Journal of Cancer, 48(4), pp. 441-446.
11. Zwanenburg, A. et al. (2023) 'The Image Biomarker Standardization Initiative: Standardized Quantitative Radiomics for High-Throughput Image-based Phenotyping', Radiology, 308(2), e221422.
12. Chen, R.J. et al. (2023) 'Towards a General-Purpose Foundation Model for Computational Pathology', Nature Medicine, 29(4), pp. 850-862.
13. Kather, J.N. et al. (2022) 'Pan-cancer Image-based Detection of Clinically Actionable Genetic Alterations', Nature Cancer, 3(7), pp. 789-799.
14. Chaudhary, K. et al. (2021) 'Deep Learning-Based Multi-Omics Integration Robustly Predicts Survival in Liver Cancer', Clinical Cancer Research, 27(5), pp. 1248-1259.
15. Cancer Genome Atlas Research Network (2013) 'The Cancer Genome Atlas Pan-Cancer Analysis Project', Nature Genetics, 45(10), pp. 1113-1120.
16. Huang, S.C. et al. (2021) 'Self-supervised Learning for Medical Image Classification: A Systematic Review', IEEE Transactions on Medical Imaging, 40(8), pp. 2021-2037.
17. Moor, M. et al. (2023) 'Foundation Models for Generalist Medical Artificial Intelligence', Nature, 616(7956), pp. 259-265.
18. Lambin, P. et al. (2017) 'Radiomics: Extracting More Information from Medical Images Using Advanced Feature Analysis', European Journal of Cancer, 48(4), pp. 441-446.
19. Zwanenburg, A. et al. (2023) 'The Image Biomarker Standardization Initiative: Standardized Quantitative Radiomics for High-Throughput Image-based Phenotyping', Radiology, 308(2), e221422.
20. Chen, R.J. et al. (2023) 'Towards a General-Purpose Foundation Model for Computational Pathology', Nature Medicine, 29(4), pp. 850-862.
21. Kather, J.N. et al. (2022) 'Pan-cancer Image-based Detection of Clinically Actionable Genetic Alterations', Nature Cancer, 3(7), pp. 789-799.
22. Chaudhary, K. et al. (2021) 'Deep Learning-Based Multi-Omics Integration Robustly Predicts Survival in Liver Cancer', Clinical Cancer Research, 27(5), pp. 1248-1259.
23. Cancer Genome Atlas Research Network (2013) 'The Cancer Genome Atlas Pan-Cancer Analysis Project', Nature Genetics, 45(10), pp. 1113-1120.
24. Huang, S.C. et al. (2021) 'Self-supervised Learning for Medical Image Classification: A Systematic Review', IEEE Transactions on Medical Imaging, 40(8), pp. 2021-2037.
25. Moor, M. et al. (2023) 'Foundation Models for Generalist Medical Artificial Intelligence', Nature, 616(7956), pp. 259-265.
26. Hanahan D. Hallmarks of cancer: new dimensions. Cancer Discov. 2022;12(1):31–46. Doi:10.1158/2159-8290.CD-21-1059.
27. Singhal K, Azizi S, Tu T, et al. Large language models encode clinical knowledge. Nature. 2023;620(7972):172–180. Doi:10.1038/s41586-023-06291-2.
28. Xu H, Usuyama N, Bagga J, et al. A whole-slide foundation model for digital pathology from real-world data. Nature. 2024;630(8015):181–188. Doi:10.1038/s41586-024-07441-w.
29. Moor M, Banerjee O, Abad ZSH, et al. Foundation models for generalist medical artificial intelligence. Nature. 2023;616(7956):259–265. Doi:10.1038/s41586-023-05881
30. Bommasani R, Hudson DA, Adeli E, et al. On the opportunities and risks of foundation models. arXiv. 2021. Doi:10.48550/arXiv.2108.07258.