Advancements and Ethical Governance of Artificial Intelligence in Oncology

A Comprehensive Clinical & Regulatory Briefing — Technical Whitepaper

EXECUTIVE SUMMARY

The oncology landscape is undergoing a paradigm shift driven by the integration of Artificial Intelligence (AI) and Machine Learning (ML). This evolution is characterized by a transition from narrow, task-specific models toward versatile foundation models (FMs) and multimodal frameworks capable of processing diverse data streams—including histopathology images, genomics, and clinical text (Niu et al., 2025; Zhang et al., 2024). As of late 2025, the U.S. Food and Drug Administration (FDA) has authorized 1,451 AI/ML-enabled medical devices, with 76% concentrated in radiology (IntuitionLabs, 2026). While these technologies promise to enhance diagnostic accuracy, optimize radiotherapy dose calculation, and improve clinical trial prescreening, significant challenges remain regarding evidence gaps, algorithmic bias, and the 'black box' nature of deep learning (Hantel et al., 2022; Sadoughi & Orooji, 2025). Ethical deployment necessitates a transition from static regulatory reviews to life-cycle management and the adoption of robust process frameworks like 'Accountability for Reasonableness' (A4R-OAI) to ensure patient autonomy and equity (Hantel et al., 2022; IntuitionLabs, 2026).

I. Technical Innovations in Oncology AI

A. Multimodal and Pan-Cancer Frameworks

Existing prognostic models have historically followed a "per-cancer-per-model" paradigm, which limits their generalization across different diseases. The Unified Multi-modal Pan-cancer Survival Network (UMPSNet) represents a breakthrough by integrating six distinct data modalities to predict survival across multiple cancer types (Zhang et al., 2024).

- **Data Integration:** UMPSNet utilizes histopathological whole slide images (WSI), genomic expression profiles, and four types of metadata (demographic information, cancer type, treatment protocols, and diagnosis results).
- **Key Mechanisms:**

- **Text Templates:** Converts discrete numerical and categorical data into standardized text templates processed via a finetuned CLIP text encoder.
- **Optimal Transport (OT):** Used for aligning and fusing disparate features from different modalities.
- **Guided Soft Mixture of Experts (GMoE):** Identifies common characteristics across cancers while adaptively extracting features specific to individual cancer types.

• **Performance:** UMPSNet achieved an average concordance index (C-index) of **0.725** across five TCGA datasets, outperforming state-of-the-art methods in both separate and joint training modes (Zhang et al., 2024).

B. Shift Toward Foundation Models

Medical imaging is moving away from task-specific networks toward large-scale foundation models (FMs) pre-trained on vast, diverse datasets.

Architecture Type	Primary Characteristics	Clinical Relevance
Transformers	Utilize self-attention to model long-range dependencies; highly scalable.	Core of modern Vision Transformers (ViTs) and language models.
CNNs (ResNet/UNet)	Built-in locality bias; translation-invariant.	Excellent for local pattern recognition when training data is limited.
State-Space Models (Mamba)	Linear scaling with sequence length; recurrent alternative to attention.	Promising for very long sequential data analysis (Niu et al., 2025).
Mixture of Experts (MoE)	Activates only a subset of parameters per input token.	Enables training of models with trillions of parameters while maintaining inference efficiency.

C. Path-IO and Immunotherapy Prediction

Path-IO is a machine learning platform designed for clinical translation in metastatic non-small cell lung cancer (NSCLC). Unlike molecular approaches, it uses routinely

gathered pathology slides to identify "niches"—intratumoral structures that influence treatment response. In validation studies of over 1,000 patients, Path-IO significantly outperformed the current standard-of-care biomarker, PD-L1 expression (MD Anderson, 2026).

II. Clinical Applications and Optimization

A. Precision Radiotherapy

AI is revolutionizing radiotherapy dose calculation by addressing the limitations of traditional algorithms (e.g., Monte Carlo or Analytical Anisotropic Algorithm) in handling complex anatomical heterogeneities (Sadoughi & Orooji, 2025).

- **Deep Learning (DL):** Convolutional Neural Networks (CNNs) and transformer-based architectures provide superior spatial fidelity for dose prediction in head, neck, prostate, and lung cancers.
- **Reinforcement Learning (RL):** Shows high potential for adaptive planning scenarios where the model learns optimal delivery strategies via reward functions.
- **Evolutionary Algorithms:** Genetic algorithms (GA) are effective for multi-objective optimization, balancing tumor coverage against organ-at-risk (OAR) sparing (Sadoughi & Orooji, 2025).

B. Early Detection and Liquid Biopsy

The PANCAID project (2023–2027) is developing an AI-assisted minimally invasive blood test for the early detection of pancreatic ductal adenocarcinoma (PDAC). By analyzing liquid biopsy samples from high-risk individuals, researchers aim to identify a composite biomarker panel to detect small tumors that release only minute amounts of cellular products into the circulation (PANCAID, 2023).

C. Clinical Trial Operations

AI-human collaboration has been proven to enhance the efficiency of screening patients for clinical trials. A study at Winship Cancer Institute found that AI support in identifying complex eligibility criteria (e.g., biomarkers and staging) could allow high-volume centers to screen an additional 10 to 20 patients per week (Parikh, 2026).

III. Regulatory Landscape and Evidence Standards

A. FDA Authorization Trends

The volume of AI/ML-enabled medical device clearances has escalated dramatically over the last decade (IntuitionLabs, 2026).

Metric	2015 Data	2025 Data
Annual Clearances	6	295
Cumulative Total	<20	1,451
Radiology Share	-	76% (1,104 devices)
Pathway Dominance	-	97% via 510(k)

• **PCCPs:** In December 2024, the FDA finalized guidance on Predetermined Change Control Plans (PCCPs), allowing manufacturers to pre-specify algorithm updates. In 2025, 10% of clearances included these plans.

• **Foundation Models:** February 2025 marked the first FDA clearance of a foundation model-powered clinical AI device (Aidoc CARE1™), adapting multi-task algorithms to clinical use cases (IntuitionLabs, 2026).

B. Critical Evidence Gaps

> **Methodological Evidence Notice**
> Despite the surge in approvals, rigorous clinical validation remains sparse. A 2025 study found that less than 2% of FDA-cleared AI/ML devices were supported by randomized clinical trials, and over 50% of FDA summaries omitted sample sizes (IntuitionLabs, 2026).

IV. Ethical Considerations and Governance

A. The A4R-OAI Framework

To address concerns regarding structural racism, bias, and the erosion of patient-oncologist relationships, a process-focused framework called Accountability for Reasonableness for Oncology AI (A4R-OAI) has been proposed (Hantel et al., 2022).

1. **Relevance:** Decisions should be based on reasons fair-minded people agree are relevant, prioritizing patient values through "value-flexible design".
2. **Publicity:** Data sets, development methods, and monitoring processes must be publicly accessible.
3. **Revision:** Establishing formal plans for longitudinal monitoring to guard against emergent biases.
4. **Empowerment:** Minizing power differences between developers, oncologists, and patients; ensuring minority opinions are monitored.
5. **Enforcement:** Implementing voluntary or public regulation to ensure the first four conditions are met.

B. Bias and Autonomy

Ethical concerns center on the "black box" nature of AI. Models trained to maximize specific outcomes like overall survival may disregard patient preferences, subtly undermining autonomy (Hantel et al., 2022). Furthermore, models built on biased data—such as oncology biobanks where non-Hispanic Whites are over-represented—risk exacerbating care inequities (Hantel et al., 2022).

V. Future Directions: Digital Twins and Beyond

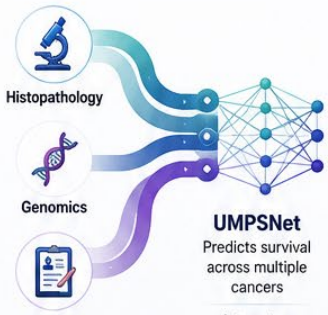
The ultimate goal for oncology AI is the realization of the "digital twin"—a personalized, virtual mathematical model of an individual patient's tumor. By drawing on routine MRI scans to track tumor size, blood flow, and cell behavior, clinicians can use these twins to predict the optimal way to intervene, moving away from a one-size-fits-all treatment approach (Yankeelov, 2026). Future milestones will include the full integration of multimodal data (genomics, CT imaging, and clinical variables) into these predictive platforms (MD Anderson, 2026).

The New Frontier: AI-Driven Precision Oncology

The rapid advancement and integration of AI in cancer care, from diagnosis to ethical governance.

TECHNOLOGICAL FRONTIERS IN DETECTION & PROGNOSIS

Pan-Cancer Multi-Modal Learning



UMPSNet
Predicts survival across multiple cancers

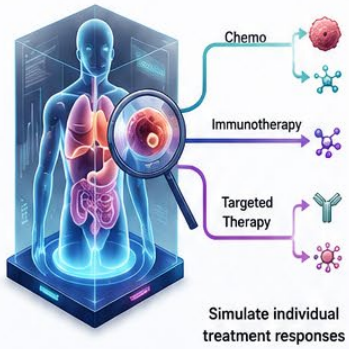
integrates histopathology, genomics, and medical records

Outperforming Standard Biomarkers

Current PD-L1 Testing
Predicts lung cancer immunotherapy response more accurately

Path-IO Model
Predicts lung cancer immunotherapy response more accurately

Personalized "Digital Twins"



Simulate individual treatment responses

GOVERNANCE, ETHICS, AND THE REGULATORY SURGE

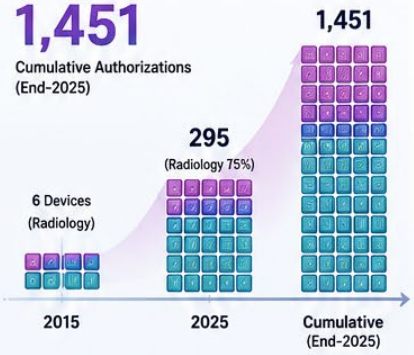
The Ethical "A4R-OAI" Framework

Process-focused approach ensuring AI empowerment of oncologists and patients

Human-AI Collaboration

Pairing AI with human reviewers improves clinical trial prescreening accuracy for complex biomarkers

1,451 FDA-Authorized AI Devices



KEY TAKEAWAY

- AI is transforming cancer care through integrated data, advanced modeling, and personalized solutions.
- Ethical frameworks and human-AI collaboration ensure trust, transparency, and better outcomes.
- Regulatory momentum is accelerating the safe adoption of AI technologies in clinical practice.
- Together, AI and human expertise are shaping the future of precision oncology.

Smarter decisions. Better outcomes. A healthier tomorrow.
AI at the forefront of cancer care.

Precision Today. Hope for Tomorrow.

References

Hantel, A., Clancy, D. D., Kehl, K. L., Marron, J. M., Van Allen, E. M., & Abel, G. A. (2022). A Process Framework for Ethically Deploying Artificial Intelligence in Oncology. Journal of Clinical Oncology, 40(34), 3907-3911.

IntuitionLabs. (2026). FDA's AI Medical Device List: Stats, Trends & Regulation.

MD Anderson Cancer Center. (2026). AACR: New platform uses machine learning to predict responses in patients with lung cancer.

Niu, C., Wu, P., De Man, B., & Wang, G. (2025). Foundation Models for Medical Imaging: Status, Challenges, and Directions. arXiv.

PANCAID. (2023). PANCAID: EU-funded project to develop a blood test for early detection of pancreatic cancer kicks off [Press Release].

Parikh, R. B. (2026). Study shows AI can help identify more patients for cancer clinical trials. Nature Communications (via Winship Cancer Institute).

Sadoughi, H. R., & Orooji, A. (2025). Leveraging Advanced AI Technologies for Radiotherapy Dose Calculation: A Narrative Review. Trends in Advanced Technologies in Medicine, 1(1).

Yankeelov, T. (2026). Transforming Cancer Treatment Through Digital Innovation. UT Austin News.

Zhang, B., Li, S., Jian, J., Meng, Z., Guo, L., & Zhao, Z. (2024). A Multi-Modal Deep Learning Framework for Pan-Cancer Prognosis. arXiv.