

ARTIFICIAL INTELLIGENCE

Artificial Intelligence in Cancer Care: Addressing Challenges and Health Equity

ABSTRACT

Overdiagnosis in cancer care remains a significant concern, often resulting in unnecessary physical, emotional, and financial burdens on patients. Artificial intelligence (AI) has the potential to address this challenge by enabling more accurate, personalized cancer diagnoses and facilitating tailored treatment plans. Integrating AI with precision medicine can minimize unnecessary treatments and associated adverse effects by optimizing care strategies based on individual patient data. However, the integration of AI in oncology requires rigorous research and validation to ensure its effectiveness across diverse populations and clinical settings. Challenges such as algorithmic bias, data representation, and limited access to technology in resource-constrained settings highlight the need for equitable AI applications in health care. Addressing health equity disparities is critical, as diverse and representative training data sets significantly affects the fairness and efficacy of AI systems. AI also holds promise for advancing cancer care in resource-limited settings by providing cost-effective diagnostic tools, democratizing access to advanced health care technologies, and improving outcomes in low- and middle-income nations. Interdisciplinary and international collaborations between researchers, clinicians, and technologists are crucial to maximizing AI's potential in cancer care. By fostering these partnerships and focusing on the development of accessible, ethical, and patient-centered AI applications, the health care community can revolutionize cancer diagnosis and treatment. The growing role of AI in precision medicine brings hope for equitable, cost-effective, and improved patient outcomes worldwide.

Keywords: Artificial intelligence, precision medicine, cancer care, overdiagnosis, personalized treatment, health equity, machine learning.

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Introduction

In the US, approximately 40% of adults are diagnosed with cancer during their lifetime.^{1,2} Despite this high incidence, 608,366 Americans have died of cancer in recent years, reflecting a relatively lower mortality rate due to advancements in early detection, treatment, and imaging technologies.^{3,4} However, this mortality figure highlights the need for further progress to minimize cancer-related deaths.

Among the promising avenues for improvement, precision medicine, specifically the integration of artificial intelligence (AI), can transform cancer care. During his keynote presentation at Med-News Week, Anant Madabhushi, PhD, executive director for the

Emory Empathetic AI for Health Institute at Emory Winship Cancer Institute, discussed the role of AI in enabling more accurate cancer diagnoses, improving prognostic tools, and facilitating personalized treatment approaches.⁵ Highlights from his presentation are broken down into 3 major categories that oncologists should consider to help enhance treatment decision-making.

He emphasized how AI-powered systems can analyze vast data sets to identify subtle patterns, classify cancer subtypes, and characterize tumor microenvironments (TMEs), offering previously unattainable insights. For instance, AI applications in digital pathology unlock latent information from tumor tissue, enabling clinicians to

tailor treatment strategies to individual patient profiles.⁶

Overdiagnosis, defined as the detection of conditions that would not cause symptoms or harm, remains a critical issue in cancer care.⁷ For example, findings from breast cancer studies report overdiagnosis rates ranging from 0% to 54%, findings from with randomized trials suggesting a narrower range of 11% to 22%.⁸ This phenomenon results in unnecessary treatments that impose significant physical, emotional, and financial burdens on patients. For instance, men with low-risk prostate cancer may undergo radiotherapy, which carries risks such as erectile dysfunction and secondary cancers.⁹ Additionally, overdiagnosis contributes to unneeded health care costs, leaving many patients facing financial hardship. Approximately 42% of Americans with cancer lose their life savings during treatment.²

The synergy between AI and precision medicine offers a solution to mitigate overdiagnosis by enabling more tailored and accurate treatment strategies. AI can assess whether specific treatments are necessary, potentially sparing patients from overtreatment and its associated adverse effects. In prostate cancer, for instance, AI could prevent unnecessary radiotherapy, reducing both physical complications and financial burdens.¹⁰

However, the successful integration of AI into precision oncology requires rigorous research, calibration, and validation. AI algorithms must account for population diversity to avoid inaccuracies in diagnosis and treatment. Intentional design and testing across diverse groups are essential to ensure the reliability and equity of AI applications.¹¹ AI systems must rely on extensive, high-quality data sets to ensure accurate and reliable outcomes. Insufficient data limit the model's ability to generalize beyond the training examples, resulting in overfitting to the specific data set and poor performance on unseen or diverse data. This limitation can also lead to algorithmic bias and systematic discrimination that emerges from the inherent characteristics of the training data or the learning process.

Models trained on small or unrepresentative data sets may exhibit high accuracy within the training set but fail to generalize effectively, amplifying disparities when applied broadly. Algorithmic biases have profound implications in precision medicine, where unequal representation in data sets can exacerbate existing health disparities. For instance, if AI tools are predominantly trained on data sets from populations with greater access to health care, the resulting models are likely to perform poorly for underrepresented groups. Such biases risk perpetuating inequities by reinforcing existing health care gaps, ultimately widening the divide between well-served and underserved populations.

However, AI can also address disparities in health care by providing affordable and accessible solutions for low- and middle-income populations, thereby democratizing cancer care and reducing the financial toxicity associated with overdiagnosis. Moreover, AI-powered telemedicine and virtual care have significant potential to improve health care access, particularly in underserved regions. AI-driven tools, such as chatbots and virtual assistants, can offer medical advice and support to individuals in remote or underrepresented areas where access to physical health care services is limited. Additionally, AI technologies can address language barriers, facilitating communication between patients and health care providers.

By enabling non-native speakers to access appropriate care in their preferred language, these tools promote inclusivity and equity in health care access and delivery.

The successful integration of AI in oncology requires interdisciplinary collaboration and the development of actionable frameworks that prioritize ethical standards and patient safety. By addressing these challenges and promoting innovation, AI has the potential to transform cancer care, ensuring that the benefits of precision medicine are accessible to all patients, regardless of their socioeconomic or geographic circumstances (**Figure 1** and **Figure 2**).

The Role of AI and Deep Learning in Precision Oncology: From Tumor Analysis to Personalized Treatments

AI algorithms, particularly deep learning models, offer advanced tools for analyzing tumors and their TME. Deep learning involves neural networks designed to recognize patterns in data, such as medical imaging, through hierarchical layers; simpler features are identified in early layers, whereas deeper layers extract complex structures.¹² This capability provides insights into subtle patterns often missed by clinicians and researchers. However, for biological data sets such as genomics, clinical data, and pathology reports, deeper layers may not always improve performance, requiring tailored AI models.¹³

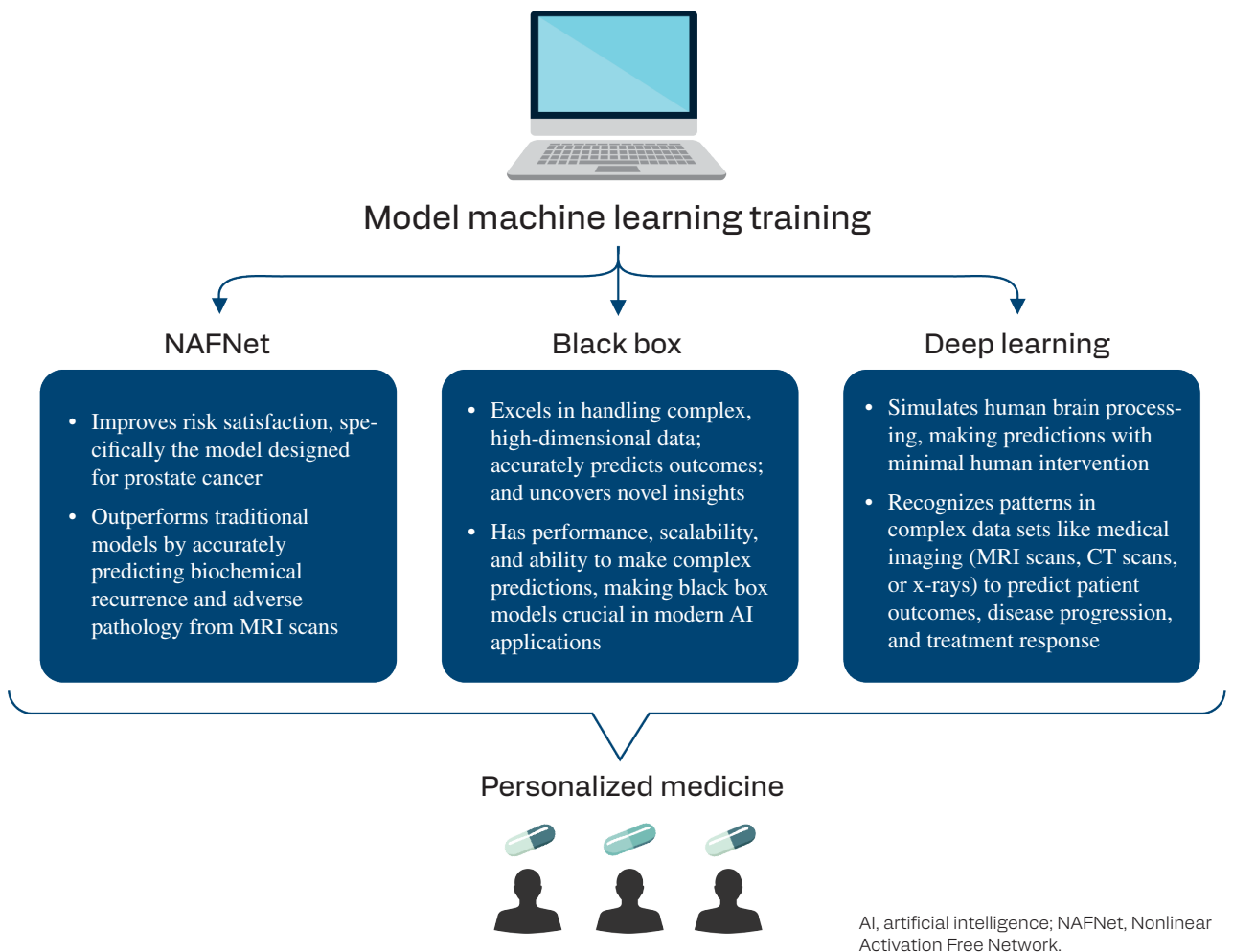
Deep learning networks, such as convolutional neural networks (CNNs), excel in pattern recognition, including identifying cell and tissue types.¹⁴ CNNs process data through sliding filters (kernels) to detect edges, shapes, and patterns in images, enabling the analysis of tissue density, cell morphology, and pathological anomalies.^{15,16} For instance, Mostavi et al used a shallow CNN model to classify tumor vs nontumor samples, achieving 93.9% to 95.0% accuracy. The model identified biomarkers such as GATA3 in breast cancer and achieved 88.42% accuracy in distinguishing breast cancer subtypes among 5 categories.¹⁷ This demonstrates CNNs' capacity to identify cancer subtypes and associated markers effectively while avoiding overfitting by employing shallower networks for biological data.

AI also facilitates radiomics, defined as the retrieval of quantitative information from medical images. Through segmentation, feature extraction, and classification, radiomics identifies tumor attributes such as size, shape, and sphericity that may be imperceptible to the human eye.^{18,19} Furthermore, AI enables pathobiological analyses, providing microscopic insights into TMEs, such as gene expression profiles and extracellular components like stromal cells and blood vessels.^{20,21} For instance, identifying mutations such as *EGFR* in non-small cell lung cancer (NSCLC) enables AI to recommend targeted therapies, such as erlotinib or ramucirumab, improving precision in treatment selection.^{22,23}

AI's ability to integrate radiomic and pathobiological data further enhances its clinical utility. By synergizing these data sets, AI can predict treatment outcomes and recommend personalized interventions.^{24,25} For example, if a tumor is identified as immunologically evasive, AI may advise against therapies such as atezolizumab, highlighting its role in optimizing combination treatments.²⁶ AI's scalability is further illustrated by Blasiak

FIGURE 1. AI-driven personalized treatment, leveraging models like NAFNet, is improving prostate cancer risk stratification by accurately predicting biochemical recurrence and adverse pathology from MRI scans. NAFNet outperforms traditional models in these areas. Black box models, which learn from vast data to identify patterns, are essential for making complex predictions and uncovering novel insights. Deep learning, simulating human brain processing, excels at recognizing patterns in complex medical data like MRI and CT scans, allowing for precise predictions of patient outcomes, disease progression, and treatment responses.

AI-Assisted Personalized Treatment



et al, who used AI to analyze 530,000 drug combinations for COVID-19, identifying the optimal therapy of remdesivir, ritonavir, and lopinavir.^{27,28} A similar approach in oncology could revolutionize combination therapy design.

Deep phenotyping is another domain where AI integration offers significant potential. Defined as the detailed analysis of phenotypic abnormalities, deep phenotyping can elucidate tumor characteristics within the TME.²⁹ Lazare et al, using multiplexed immunofluorescence, characterized tumor-infiltrating lymphocytes (TILs) and their spatial positioning in NSCLC samples.^{30,31} Although their study lacked AI integration, incorporating CNNs could have streamlined image analysis, reduced human error, and quantified

spatial relationships within the TME, such as fibroblast clustering or lymphocyte localization.

Traditional AI models, such as supervised learning (SL) algorithms, are not without limitations; they require large, labeled data sets for effective training. Labeled data sets consist of input data paired with corresponding output data that describe target outcomes—for example, gene expression levels associated with specific disease states or medical imaging scans annotated with diagnostic findings. However, in the field of precision medicine, such data sets are often scarce due to the complexity and multifaceted nature of biological data. In contrast, unsupervised learning (UL) offers a powerful alternative by enabling high-dimensional

FIGURE 2. AI-enhanced precision medicine improves cancer detection, treatment outcomes, and personalization by analyzing imaging and pathology data, offering more accurate predictions and reducing health care disparities. However, current drawbacks include the risk of overdiagnosis, potential bias due to lack of diverse data, high initial costs, and concerns over trust and complexity among health care providers.

AI-Enhanced Precision Medicine in Cancer Treatment

Pros

- AI analyzes imaging and pathology data, uncovering details that traditional methods might miss, which helps doctors make more informed treatment decisions.
- By integrating various data sources, AI helps create more tailored treatment plans based on the unique characteristics of each patient's cancer.
- AI-powered systems can be cost-effective in the long term, making them accessible to underserved populations and potentially lowering health care costs for patients, particularly in low-income areas.
- AI tools can be adjusted to account for diverse populations, helping reduce disparities in cancer care and enabling equitable access to advanced health care technologies.
- AI can make more accurate predictions about cancer progression and the likelihood of treatment response, helping physicians better plan interventions and treatment regimens.

Cons

- AI might identify cancers that would not progress or require treatment, potentially leading to overtreatment.
- If not trained on diverse, high-quality data sets, it may be less accurate for certain populations.
- Although AI tools can be cost-effective in the long run, implementing AI systems in health care can be expensive initially, especially in low-resource settings or health care systems with limited infrastructure.
- AI systems depend on extensive, high-quality data. If the data used to train AI models are incomplete or biased, it could lead to incorrect treatment recommendations.
- AI tools can be complex, and if not sufficiently transparent, physicians might struggle to understand or trust the technology.
- Physicians may fear AI could replace their expertise, undermining confidence in clinical decision-making.

AI, artificial intelligence.

analysis of unlabeled data sets. UL operates on data without pre-defined annotations—such as DNA or RNA sequences not linked to specific phenotypes or protein expression levels without associated conditions—allowing it to identify patterns and relationships autonomously.³² This capability makes UL particularly well suited to biological systems, where data are frequently vast, intricate, and unlabeled. Unlike SL, which depends on extensive manual annotation that is time intensive, laborious, and costly, UL can efficiently uncover insights without the need for labeled training data, significantly accelerating the discovery of novel biological relationships.

AI's transformative capabilities in cancer care, from tumor characterization to treatment optimization, support its potential to redefine precision medicine. With ongoing advancements, AI can significantly enhance diagnostic accuracy, reduce human error, and ultimately improve therapeutic outcomes.

Pathomics and AI: Transforming Prognostic Tools in Breast and Prostate Cancer

A major challenge in breast cancer treatment is determining which patients benefit from chemotherapy vs those who can avoid it with minimal added risk. About 2 decades ago, a gene expression-based test developed by Genomic Health revolutionized treatment by identifying patients who may benefit from surgery and hormonal therapy alone.³³ However, these tests face limitations, including high costs and susceptibility to tumor heterogeneity, where sampled areas may not reflect the tumor's most aggressive regions. This limitation can lead to inaccurate risk scores that fail to capture a tumor's true potential for progression.

Pathomics, the application of machine learning (ML) to digital pathology, has emerged as a promising alternative or complement to genomic tests. Digital pathology enables cloud-based analysis

and algorithm-driven predictions without tissue destruction. For instance, in breast cancer, ML approaches have been employed to study tumor-associated collagen.³⁴ Madabhushi's team introduced the image-based risk score (IbRiS), which provides additional prognostic value to Oncotype DX for estrogen receptor–positive breast cancer.³⁵ IbRiS identifies patients who have high risk within low Oncotype DX categories, indicating those who could benefit from chemotherapy despite being classified as low risk. Compared with genomic tests, IbRiS offers improved cost-effectiveness and granularity while mitigating challenges posed by tumor heterogeneity.

The potential of AI-based tools extends beyond breast cancer. In prostate cancer, combining imaging features with clinical variables, such as Gleason grade and prostate-specific antigen (PSA) levels, has shown significant promise. An image-based approach outperformed the \$3000 Decipher test, demonstrating the potential for better outcomes at reduced costs.³⁶ These tools are especially impactful in addressing health disparities, as study results reveal African American patients disproportionately experience aggressive prostate cancer due to barriers such as systemic racism and disease biology. For example, stromal differences between Black and White patients were identified in a systematic analysis of prostate cancer cases.³⁷

Recent AI advancements include Nonlinear Activation Free Network (NAFNet), a deep learning model published in 2023, which predicts adverse pathology and recurrence risk using MRI data. Analyzing over 500 patients, NAFNet demonstrated superior predictive accuracy over traditional clinical scores, such as Prostate Imaging Reporting and Data System and Cancer of the Prostate Risk Assessment, offering improved risk stratification in prostate cancer management.³⁸ Similarly, findings from another study highlighted the promise of AI-based tools in predicting biochemical recurrence (BCR) after radical prostatectomy. BCR, marked by rising PSA levels after initial treatment, often signals recurrence or metastasis.³⁹ However, these AI models require further prospective studies and external validation to achieve widespread clinical implementation.

These advancements highlight the transformative potential of AI in oncology, offering cost-effective, accessible, and accurate prognostic tools. They pave the way for personalized treatment plans and help address disparities in cancer outcomes across diverse populations.

Population-Specific AI in Oncology: Advancing Precision and Equity in Cancer Care

In the evolving landscape of AI in health care, the development of population-specific AI models has become a critical focus. These models must be intentionally designed to account for the diverse characteristics of different populations, as data representation in training and discovery sets significantly affects the efficacy of AI applications in clinical settings. One example is the use of machine learning to identify the multinucleation index (MuNI) in oropharyngeal cancers. This value, which measures large cancer nuclei that intersect or touch, provides crucial prognostic information. AI algorithms that analyze pathology images for micronucleation can enhance predictive capabilities, particularly when validated across

diverse populations and clinical environments.⁴⁰

Recent research underscores the importance of population-specific factors in cancer prognosis. Combining MuNI with the spatial distribution of TILs improves prognostic accuracy, particularly for patients exhibiting specific genetic mutations. These findings emphasize the role of tailored AI models in predicting outcomes and guiding personalized treatment strategies.⁴¹ In NSCLC, the spatial configuration of immune cells has proven predictive of immunotherapy responses, enabling clinicians to identify candidates for monotherapy immunotherapy and avoid unnecessary chemotherapy. This tailored approach significantly enhances therapeutic strategies and outcomes for patients with NSCLC.⁴²

AI has also advanced the development of imaging biomarkers, providing innovative diagnostic tools. For instance, the collagen texture feature differentiates between radiation necrosis and tumor recurrence on MRI scans by applying voxel-based color maps. This technique enhances diagnostic precision in patients with brain tumors.⁴³ Similarly, the overexpression of collagen outside tumors has been correlated with complete cancer clearance post surgery, whereas underexpression indicates residual malignancy. These insights advocate for AI-driven image analysis as a valuable reference in treatment planning, particularly in human papillomavirus–related oropharyngeal carcinoma.⁴⁴

The application of population-specific AI models is particularly impactful in low- and middle-income countries, where they offer cost-effective diagnostic solutions. AI tools can democratize access to advanced health care technologies, improving outcomes and resource allocation. Remote diagnostics powered by AI reduce the burden on health care systems, addressing disparities in access and enabling more equitable care.^{45,46} Transparency and explainability in AI algorithms are also crucial for enhancing trust among health care professionals. Enhancing the transparency of AI models is crucial for understanding the rationale behind their decisions. This, coupled with the application of diverse data sets, ensures that AI tools operate equitably and efficiently across populations, minimizing the risk of disproportionately benefiting specific groups to the detriment of others—a scenario that could adversely affect patient outcomes.⁴⁷

The wide-ranging potential of AI in oncology is exemplified by its success across various cancer types. For instance, Madabhushi's team developed the IbRiS, which integrates ML with digital pathology to provide superior prognostic capabilities for patients with breast cancer, identifying individuals at high risk who might benefit from chemotherapy.⁴⁸ Similarly, the deep learning model NAFNet demonstrates remarkable predictive accuracy in prostate cancer, using MRI data to assess adverse pathology and recurrence risk, thereby supporting clinical decision-making.⁴⁹ AI applications in lung cancer have also revealed critical insights, such as the spatial distribution of TILs, which aid in predicting responses to immunotherapy.⁵⁰ Moreover, AI-driven radiomic techniques have proven effective in distinguishing between tumor recurrence and radiation necrosis in brain tumors, showcasing their diagnostic precision.⁵¹ Notably, AI has also played a pivotal role in addressing health disparities, particularly in low- and middle-

income countries, by developing population-specific models that improve access to cancer care resources⁵² (Table).

Conclusion

The integration of AI and ML technologies has transformed health care, providing innovative tools for disease diagnosis and treatment planning. Advances in pathomics and deep learning models such as NAFNet demonstrate AI’s potential to predict clinical outcomes with precision, offering noninvasive, reliable methods that can revolutionize clinical decision-making.⁵⁴ Population-specific AI models are vital to ensure equitable health care, requiring diverse data sets and rigorous testing to enhance generalizability and minimize biases.⁵⁵

Health care organizations must prioritize implementing transparent and accountable algorithms, regular audits to eliminate bias, and training for professionals to interpret AI-generated insights effectively. Developing actionable frameworks to integrate AI into existing workflows while maintaining ethical standards is essential. Collaboration among clinicians, data scientists, and ethicists will support the seamless integration of AI in health care.⁵⁶

Ethical considerations such as data security, transparency, and clinical validation are crucial to fostering trust and ensuring responsible AI adoption.⁵⁷ Addressing algorithmic bias and improving explainability will optimize AI’s role in enhancing patient care.⁵⁸ Future research should validate tools such as the NAFNet-based deep learning nomogram in diverse populations and focus on creating clear guidelines for AI implementation in clinical settings.

Low-cost, accessible AI tools can promote inclusivity, advancing equitable health care. By prioritizing transparency, ethical design, and interdisciplinary collaboration, AI systems can drive meaningful progress in personalized medicine. Future exploration of AI applications should balance technological innovation with ethical

responsibility, ensuring patient well-being remains central. AI’s evolving role in personalized cancer treatment offers a promising path toward improving outcomes and making care accessible to all. ■

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Conceptualization, VC, JG; methodology, VC, JG, and AT; formal analysis, VC, JG, AT, KI, VJR, CHP, and YL; investigation, VC, JG, AT, KI, VJR, CHP, and YL; resources, VC, JG, AT, KI, VJR, CHP, and YL; data curation, VC, JG, AT, KI, VJR, CHP, and YL; writing—original draft preparation, VC, JG, AT, KI, VJR, CHP, and YL; writing—review and editing, VC and JG; visualization, VC, JG, AT, KI, VJR, CHP, and YL; supervision, CHP and YL; project administration, VC, JG, CHP, and YL. All authors have read and agreed to the published version of the manuscript and jointly affirm the accuracy of this work. All authors consent to its submission for publication.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

 FOR REFERENCES VISIT cancernetwork.com/4.25_AI

TABLE. Key Studies Employing AI Methodologies Across Various Cancer Types

STUDY	CANCER TYPE	METHODOLOGY	KEY FINDINGS/OUTCOMES
Verma et al (2018) ⁴⁸	Breast cancer	Shallow CNN classification	93.9%-95.0% accuracy in classifying tumors
Gu et al (2023) ⁴⁹	Prostate cancer	MRI deep learning model	Superior predictive accuracy for adverse pathology
Park et al (2022) ⁵⁰	Lung cancer	Spatial analysis of type 1 immune cells	Predictive of immunotherapy responses
Basree et al (2024) ⁵¹	Brain tumors	Radiomic analysis	Successfully differentiates between necrosis and recurrence
Ngaim et al (2019) ⁵²	Various	AI in LMICs	Improved access and outcomes in cancer care
Gao et al (2018) ⁵³	General oncology	Population-specific models	Tailored AI that improves treatment predictions

AI, artificial intelligence; CNN, convolutional neural network; LMICs, low- and middle-income countries.