WEP Warwick Evans Publishing

Transactions on Materials, Biotechnology and Life Sciences
ISSN: 2960-1932, eISSN: 2960-2319 | Volume 8
MMTCS 2025

Applications of Artificial Intelligence in Cancer Precision and Personalized Medicine

Shili Sun *

College of Arts & Sciences, University of Washington, Seattle, WA, United States

* Corresponding Author Email: sunshili0226@gmail.com

Abstract. Artificial Intelligence (AI), as a rapidly evolving technology, is fundamentally transforming the diagnosis and treatment of cancer. This article systematically discusses the research and application progress of AI in key areas such as medical image analysis, genomic data interpretation, personalized treatment design, and clinical decision support. In medical imaging, AI, powered by deep learning, significantly enhances the sensitivity and accuracy of tumor detection in CT, MRI, and other scans, reduces human error, and enables multi-lesion monitoring and dynamic tumor tracking. In genomic data interpretation, AI can accurately identify cancer-related driver mutations and biomarkers, accelerating early screening and risk prediction, and providing a scientific basis for personalized treatment plans. Meanwhile, AI's application in drug discovery and cancer immunotherapy continues to expand, improving drug candidate prediction efficiency and accurately predicting immune therapy responses to optimize treatment combinations. AI-assisted clinical decision systems integrate multimodal data to provide individualized treatment suggestions, facilitating the transition of cancer therapy from experience-based to data-driven methods. Although challenges such as data privacy, model interpretability, and ethical concerns remain, AI holds great promise in cancer precision medicine and is poised to become a vital component of future oncology care.

Keywords: Artificial Intelligence; Personalized Medicine; Cancer Precision.

1. Introduction

Cancer is one of the leading causes of death worldwide. However, with advances in technology, numerous innovations have emerged to improve both the survival rate and quality of life for cancer patients. These include genetic analysis for risk prediction, early diagnosis through medical imaging, precision therapies, and personalized treatment approaches. Over the past few decades, the rapid accumulation of genomic, imaging, and clinical data—along with technological breakthroughs—has rendered traditional research methods insufficient for effectively integrating and analyzing massive datasets. In the past ten years, artificial intelligence (AI) technologies have made significant strides, especially in the last three years, demonstrating powerful capabilities in data processing and deep learning. These advancements are poised to transform traditional cancer diagnosis and treatment, offering robust technical support for early cancer screening, precise diagnosis, and the design of personalized therapeutic strategies. By integrating data from various sources, AI can analyze the molecular characteristics of cancer and assist physicians in delivering more accurate tumor classification, risk prediction, and drug selection—paving the way for true precision medicine and personalized care.

The major application areas of AI in cancer research include medical image analysis, refined screening and interpretation of genomic data, drug development, and clinical decision support. In terms of medical imaging, AI has been widely applied to identify and quantify tumor features. Traditionally, interpreting medical images such as CT, MRI, and X-rays required experienced specialists, and diagnostic outcomes often varied based on individual expertise. Different doctors might even interpret the same image differently. AI, however, can automatically extract complex features from these medical images through deep learning, while filtering out irrelevant data. Given sufficient training data, AI's diagnostic accuracy can surpass the average performance of human physicians. Integrating AI with medical imaging not only improves the sensitivity of tumor detection but also enables dynamic monitoring of tumor growth and parallel tracking of multiple lesions. According to research published in the Wiley journal, AI has made breakthrough progress in automatically quantifying tumor size, identifying genotype-phenotype features, and integrating multimodal imaging data—greatly enhancing diagnostic and follow-up efficiency in cancer care [1]. In genomic data analysis, AI can precisely interpret each patient's genetic sequence through deep learning, identifying cancer-related biomarkers and genes. This allows physicians to proactively develop treatment plans based on the data, reducing an individual's risk of developing cancer—ultimately contributing to lifespan extension. A study published in The Lancet showed that AI significantly improves the accuracy of detecting tumor-driving genes by recognizing patterns and predicting mutations within genomic data, thus advancing early cancer intervention and personalized treatment [2]. In drug discovery, AI can accelerate the development of new therapies, especially demonstrating enormous potential in the field of cancer immunotherapy. For instance, researchers at the National Cancer Institute (NCI) used machine learning to analyze T-cell activation data from both humans and mice, predicting how T-cells respond to tumors, which can help optimize immunotherapy strategies [3]. Additionally, AI supports clinical decision-making. Scientists can train AI systems on vast datasets, allowing AI to rapidly and accurately extract complex patient characteristics. By integrating a patient's clinical history and genetic features, AI can match them to the most similar cases in the database, assisting doctors in formulating optimal treatment plans. This helps reduce side effects and prolong survival time. Such intelligent decision-support systems are driving a shift from experience-based medicine to data-driven medicine [4]. By assisting physicians in clinical decisions, AI can also help address the issue of uneven medical standards across different regions.

2. AI Applications in Cancer Imaging Diagnosis and Prediction

2.1. Background: Deep Learning in Medical Image Analysis

Medical imaging serves as a crucial foundation for cancer diagnosis, and the accuracy of image interpretation directly impacts patient survival rates. Traditional imaging analysis methods heavily rely on the subjective expertise of radiologists, which introduces variability and uncertainty into diagnostic outcomes. Inaccurate interpretation of medical images by physicians may lead to misjudgments about a patient's condition, resulting in the application of inappropriate treatment strategies and potentially causing patients to miss the optimal window for intervention. In more severe cases, the complexity of imaging features can lead to misdiagnosis, where a healthy individual is incorrectly identified as having cancer and subjected to unnecessary surgeries that remove healthy organs.

With the explosive growth of imaging data, conventional manual analysis is reaching its limits, creating an urgent need for more efficient, stable, and accurate assistive technologies. Deep learning techniques—particularly convolutional neural networks (CNNs)—have emerged as a dominant tool in medical image analysis due to their powerful capabilities in feature extraction and pattern recognition. CNNs can automatically extract multi-scale and hierarchical features from images through layered neural networks, enabling automated tumor detection, segmentation, quantification, and other critical tasks [5,6]. For example, a study by You et al. demonstrated that AI image recognition models have outperformed experienced radiologists in detecting cancers such as breast cancer, lung cancer, and brain tumors. In particular, the application of AI in mammography screening for breast cancer has significantly improved both sensitivity and accuracy [4].

2.2. Current Deep Learning Models and Their Applications in Medical Image Analysis

At present, the mainstream deep learning models applied in medical image analysis include Convolutional Neural Networks (CNNs), Recurrent Neural Networks (RNNs), Graph Neural Networks (GNNs), and Generative Adversarial Networks (GANs). Among these, CNNs are particularly well-suited for image data due to their architecture, and thus have become the predominant models in cancer imaging analysis.

Numerous AI models are currently undergoing testing, and some have already been implemented in clinical settings. For example, in lung cancer screening, AI models can rapidly analyze CT images to identify pulmonary nodules and assign risk scores. One study reported that AI achieved a sensitivity of over 94% in detecting lung nodules, significantly improving the efficiency of early lung cancer screening [6]. When AI is combined with physicians' expertise, it effectively enhances diagnostic accuracy and timeliness. In the case of rare diseases or atypical cases, where limited sample data is available for both physicians and AI models, data bias becomes a major issue. In such scenarios, GANs can be utilized to augment medical images and complete missing data, thereby improving overall model performance. Recently, multimodal AI systems have also emerged, which integrate and analyze diverse data types such as MRI, CT, PET scans, pathological images, and electronic medical records. These systems further enhance diagnostic accuracy and the precision of treatment planning. For instance, in imaging analysis for glioma patients, AI can fuse multiple imaging modalities to predict tumor grading and patient prognosis, aiding in the formulation of personalized treatment strategies.

2.3. Advantages and Challenges of Deep Learning in Medical Image Analysis

The application of AI in medical image analysis offers numerous advantages. First, due to its high-throughput processing capabilities, AI can analyze thousands of images within a short period, greatly enhancing diagnostic efficiency compared to human physicians. Second, when properly trained, AI models exhibit high consistency and reproducibility across various clinical scenarios. After learning from a sufficiently large number of cases, AI can deliver more accurate diagnoses, significantly reducing dependence on highly experienced specialists. Moreover, AI demonstrates exceptional sensitivity in lesion detection, capable of extracting critical features from complex imaging data. It is particularly effective in identifying early-stage, subtle, or hard-to-detect cancerous changes, thereby improving the accuracy of early cancer screening. In addition, AI possesses dynamic tracking capabilities, enabling longitudinal analysis of patient data. This allows real-time monitoring of tumor progression and can assist physicians in adjusting treatment strategies promptly.

However, despite its promising potential, the integration of AI into clinical imaging practice still faces several challenges. First, AI requires extensive training on large datasets to achieve high diagnostic accuracy. The acquisition and annotation of medical imaging data are often hindered by privacy concerns and the need for high-quality manual labeling, which increases the complexity and cost of data preparation. Second, the generalizability of AI models is limited. Variations in imaging equipment and data formats across hospitals can hinder model training and reduce diagnostic accuracy. Furthermore, deep learning models often lack interpretability, making it difficult for clinicians to understand the reasoning behind AI-generated decisions. This lack of transparency can undermine clinical trust and adoption. More critically, the involvement of AI in medical decision-making raises ethical and legal issues, such as liability attribution and privacy breaches, which require the development of comprehensive regulatory frameworks.

According to related studies, advancing AI imaging technologies from research to clinical application will require the establishment of cross-institutional data-sharing platforms, standardized model evaluation protocols, and improved physician understanding of AI outputs. These measures will support the development of efficient, human-AI collaborative diagnostic and treatment models [2].

3. AI in Precision Medicine and Personalized Treatment

3.1. The Role of AI in Genomic Data Interpretation

3.1.1. AI for Identifying Cancer-Related Mutations and Genetic Biomarkers

Cancer is fundamentally a disease caused by genetic mutations, and each patient carries a unique set of genes with varying probabilities of mutation. Traditional genomic data analysis is time-consuming and highly complex, making truly individualized interpretation difficult. AI—particularly when enhanced through deep learning—can efficiently identify potential oncogenic mutations and characteristic biomarkers within massive genomic datasets. For example, AI can perform multidimensional data modeling to screen for driver mutations and specific biomarkers in whole-genome sequencing data, supporting early cancer detection and subtype classification. Experimental studies have demonstrated that AI-based mutation prediction tools can accurately identify high-risk cancer-related genes such as TP53, BRCA1/2, and EGFR, thereby facilitating early intervention and proactive risk alerts for patients [7].

3.1.2. AI for Designing Personalized Treatment Plans

After identifying key mutations, AI can further integrate clinical data, drug databases, and treatment response information to assist physicians in formulating personalized therapeutic strategies. Using graph learning or knowledge graph–based reasoning, AI can match patients with specific mutations to the most suitable targeted or immunotherapy options. Xu et al. reported that AI performs exceptionally well in gene–drug matching, significantly shortening the time from mutation identification to treatment initiation and improving the precision of therapy. For example, in breast cancer patients with BRCA1 mutations, AI can prioritize the recommendation of PARP inhibitors and predict potential adverse reactions [8].

3.2. Breakthroughs of AI in Drug Screening and Immunotherapy

3.2.1. AI Accelerates Drug Discovery and Treatment Optimization

One of the major obstacles in cancer treatment is the long development cycle and high cost of new drug discovery. However, the integration of AI into drug development significantly accelerates the processes of compound screening and lead compound prediction. Machine learning–based drug screening platforms can efficiently predict anticancer activity and target affinity across massive compound libraries, thereby improving the efficiency of drug discovery. According to Hunter et al., AI not only enables virtual screening but also predicts the ADMET (absorption, distribution, metabolism, excretion, and toxicity) properties of candidate drugs. This helps optimize drug combinations and reduces the risk of resource waste in drug development [3].

3.2.2. AI Empowering Cancer Immunotherapy

AI plays an especially prominent role in cancer immunotherapy. The effectiveness of immunotherapies—such as PD-1/PD-L1 inhibitors or CAR-T cell therapies—is heavily influenced by factors like the patient's immune microenvironment and tumor mutation burden. AI can support immunotherapy by analyzing data such as T-cell activation states and cytokine expression levels within tumor tissues, predicting whether a patient is likely to respond to such treatments. Researchers at the U.S. National Cancer Institute (NCI) have applied AI models to analyze T-cell activation trajectories in both mice and humans, effectively predicting immune response outcomes. These insights are now being used to optimize clinical immunotherapy combination strategies [9]. Such research provides a theoretical foundation for designing dynamic, patient-specific immunotherapy pathways.

4. Future Directions of AI-Driven Precision Oncology

4.1. A Data-Driven and Multidisciplinary Precision Medicine Model

With the advancement of AI, precision oncology is becoming increasingly data-centric, integrating disciplines such as bioinformatics, radiomics, and clinical medicine to build a multimodal collaborative analysis platform. Traditionally, each discipline required its own specialist, and collaboration was often inefficient due to limited cross-disciplinary knowledge. However, with deep learning, AI can serve as a bridge connecting these fields, playing a key role in data integration, feature learning, and knowledge discovery. For instance, by integrating a patient's genomic, metabolomic, and radiomic data, AI can help physicians uncover cross-modal patterns, enabling more precise tumor identification and treatment response prediction. This integrated approach facilitates truly personalized, patient-centered care.

4.2. Prospects and Challenges of AI in Clinical Decision-Making and Personalized Treatment

AI-assisted clinical decision support systems (CDSS) have already been piloted in several oncology centers [10,11]. These systems analyze patient histories, medical images, and genomic data in combination with clinical guidelines and past clinical experiences to recommend personalized treatment plans. AI can rapidly search vast case databases to find similar patients, predict treatment responses, and estimate survival outcomes, thereby supporting more informed and evidence-based clinical decisions. Nevertheless, the clinical application of AI still faces significant challenges. These include poor model interpretability, the "black box" nature of many algorithms hindering regulatory approval, and skepticism among clinicians regarding AI-generated recommendations. Moreover, ethical concerns and data privacy protections remain major constraints. As Zhao et al. point out, the successful clinical deployment of AI must be based on trustworthy and auditable model frameworks, along with reinforced mechanisms for human–AI collaboration [5].

5. Conclusion

This study systematically analyzed the key applications of AI in cancer diagnosis and treatment, with a focus on core areas such as medical image analysis, genomic interpretation, personalized therapy, and clinical decision support. The findings indicate that AI, through deep learning, can accurately identify tumor features in medical images, enhancing the sensitivity and precision of cancer screening. In domains such as breast and lung cancer screening, AI has already outperformed traditional physician-based assessments. Furthermore, AI demonstrates strong potential in genomic data analysis, enabling the identification of key oncogenic mutations and assisting in the formulation of personalized treatment strategies. In addition, AI accelerates drug screening and optimizes cancer immunotherapy, offering new pathways for precision medicine. Despite these technological advances, the clinical implementation of AI still faces challenges, including data privacy concerns, limited model interpretability, and ethical and legal considerations. Looking ahead, it is essential to establish cross-disciplinary data integration platforms and auditable model frameworks to promote the development of efficient, trustworthy, and collaborative AI-enabled precision oncology.

References

[1] Dlamini Z, Francies F Z, Hull R, et al. Artificial intelligence (AI) and big data in cancer and precision oncology. Computational and structural biotechnology journal, 2020, 18: 2300-2311.

[2] Bi W L, Hosny A, Schabath M B, et al. Artificial intelligence in cancer imaging: clinical challenges and applications. CA: a cancer journal for clinicians, 2019, 69(2): 127-157.

[3] Hunter B, Hindocha S, Lee R W. The role of artificial intelligence in early cancer diagnosis. Cancers, 2022, 14(6): 1524.

[4] You Y, Lai X, Pan Y, et al. Artificial intelligence in cancer target identification and drug discovery. Signal Transduction and Targeted Therapy, 2022, 7(1): 156.

[5] Zhao Y, Pan Z, Namburi S, et al. CUP-AI-Dx: A tool for inferring cancer tissue of origin and molecular subtype using RNA gene-expression data and artificial intelligence. EBioMedicine, 2020, 61.

[6] Ramírez-Mena A, Andrés-León E, Alvarez-Cubero M J, et al. Explainable artificial intelligence to predict and identify prostate cancer tissue by gene expression. Computer Methods and Programs in Biomedicine, 2023, 240: 107719.

[7] Wan H, Yang X, Sang G, et al. CDKN2A was a cuproptosis-related gene in regulating chemotherapy resistance by the MAGE-A family in breast cancer: based on artificial intelligence (AI)-constructed pan-cancer risk model. Aging (Albany NY), 2023, 15(20): 11244.

[8] Xu J, Yang P, Xue S, et al. Translating cancer genomics into precision medicine with artificial intelligence: applications, challenges and future perspectives. Human genetics, 2019, 138(2): 109-124.

[9] Quazi S. Artificial intelligence and machine learning in precision and genomic medicine. Medical Oncology, 2022, 39(8): 120.

[10] Hamamoto R, Komatsu M, Takasawa K, et al. Epigenetics analysis and integrated analysis of multiomics data, including epigenetic data, using artificial intelligence in the era of precision medicine. Biomolecules, 2019, 10(1): 62.

[11] Biswas N, Chakrabarti S. Artificial intelligence (AI)-based systems biology approaches in multi-omics data analysis of cancer. Frontiers in oncology, 2020, 10: 588221.