



Artificial intelligence and radiological imaging in oncology: state of the art and future perspectives

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Abstract

Artificial intelligence (AI), in integration with the domain of radiogenomics, is transforming the perspective of oncology by bringing in imaging data with genomic profiles, to improve cancer diagnosis and treatment planning, and personalized therapies. AI-based models are more efficient for early detection of cancer, tumor-segmentation, and prediction of treatment responses, as seen in breast cancer radiomics applications. The developments have transformed the space for accuracy, workflow production, and reduced variability in image interpretation. It's a long journey, as there are still many challenges such as data quality, data diversity, as well as ethical issues regarding privacy and trust. Regulation barriers also push waiting time for clinical adoption as these limitations must be overcome through interdisciplinary cooperation on a very strong data governance model to maximize the integration of AI in oncology. All of the conventional imaging techniques such as X-ray, CT, MRI, and PET scan are integral for staging, detecting metastasis, and evaluating treatment response. This review highlights the transformative role of artificial intelligence (AI) in oncology, focusing on its applications in radiological imaging and radiogenomics. It demonstrates how AI integrates imaging and genomic data to enhance cancer diagnosis, treatment planning, and personalized medicine. The review also examines the benefits of AI, such as improved diagnostic accuracy, workflow efficiency, and predictive capabilities for treatment responses. Additionally, it identifies goals like data quality, interpretability, ethical concerns, and regulatory hurdles, emphasizing the need for collaborative efforts to address these issues. The review provides a comprehensive overview of AI's potential and limitations, paving the way for future advancements in oncology.

Keywords Oncology · Radiological imaging · Early cancer detection · Intelligent clinical laboratories · Diagnostic modalities

Introduction

Basic elements of oncology

Early diagnosis helps monitor and identify treatment problems, especially in lung cancer patients. Recent studies suggest that assessing respiratory sounds may be a crucial tool in detecting treatment-related interstitial lung disease (ILD) in patients receiving anti-HER2 antibody–drug conjugates. The increase in fine crackle quantification values (FCQV) prior to the diagnosis of ILD indicates that regular monitoring could be beneficial in early detection. Therefore, it is essential to integrate modern monitoring methods into clinical practice to facilitate prompt interventions and improve patient outcomes. [1].

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Table 1 Role of early detection in oncology

Aspect	Key points	Source
Early detection in lung cancer	Quantifying respiratory sounds aids in identifying interstitial lung disease earlier in anti-HER2 therapy	[1]
Education in breast cancer	Education on self-breast examination (SBE) and clinical breast examination (CBE) strengthens detection	[2]
Esophageal cancer	Early diagnosis and intervention improve survival rates significantly	[4]
Role of accurate diagnosis	Distinguishes between primary and metastatic cancers, avoiding unnecessary interventions	[5]
Intelligent clinical laboratories	Enhance treatment decision-making by presenting timely and accurate cancer data	[3]

Table 2 Traditional radiological imaging methods in oncology

Modality	Applications	Advantages	Source
X-rays	Initial evaluation for lung cancer; mammography for breast cancer detection	Rapid and accessible; detects non-palpable breast lesions	[6, 7]
CT scans	Detailed cross-sectional imaging for staging and treatment assessment in cancers like pancreatic	Detects metastases missed by standard methods; informs resectability decisions	[8]
MRI	Soft tissue imaging for brain tumors; differentiation of tumor types	High-resolution contrast; effective for brain and soft tissue malignancies	[9]
PET scans	Whole-body surveys for metastasis; evaluates tumor metabolism and viability	Predicts recurrence and guides treatment plans, especially in cervical and lung cancers	[9]

Breast cancer education can help resource-scarce areas diagnose this early stage. Education paired with SBE and CBE has been shown to improve early detection. A therapeutic pathway is needed for screening programs to succeed as well as it also ensures early discovery and rapid, proper treatment [2] Table 1.

Statistics play a crucial role in cancer diagnosis, aiding smart clinical laboratories in improving treatment effectiveness and patient outcomes [3]. Early detection enhances survival, as seen in esophageal cancer, where timely intervention lowers mortality [4]. Accurate histological analysis, as in ovarian cancer metastasizing to the breast, prevents unnecessary surgeries [5]. Imaging modalities like X-rays, CT, MRI, and PET are vital for diagnosis. X-rays, readily available, expedite lung cancer detection, preventing disease progression [6]. Mammography effectively identifies non-palpable breast cancer lesions, facilitating early diagnosis and treatment before the disease advances [7].

CT scans give accurate cross-sectional cancer staging and therapy response images. Due to its ability to detect concealed metastases, PET/CT fusion improves pancreatic cancer treatment [8]. While MRI helps diagnose brain and soft tissue cancer, PET/CT is better at detecting metastatic lesions [9] Table 2.

Applications of artificial intelligence

Artificial Intelligence (AI) has revolutionized the field of medical imaging, particularly in the early detection of lung and stomach tumors. With the help of machine learning algorithms, AI has the ability to analyze medical images with incredible accuracy, allowing for the differentiation between benign and malignant tumors. This has led to more effective treatment plans and improved outcomes for patients [10, 11].

Generative Adversarial Networks (GANs) have further advanced imaging capabilities, enabling healthcare professionals to detect tumors at an even earlier stage. By utilizing GANs, medical professionals can obtain clearer and more detailed images, leading to a more precise diagnosis and treatment plan. This technology has been particularly beneficial in the early detection of various types of cancers, including lung and stomach tumors.

In addition to its impact on tumor detection, AI has also played a crucial role in the diagnosis of COVID-19. Through the analysis of medical images, AI algorithms can identify patterns and characteristics associated with the virus, aiding in the early detection and treatment of infected individuals. This has been especially important in the midst of the global pandemic, as early identification of COVID-19 cases can help prevent the spread of the virus and improve patient outcomes [11, 12].

Furthermore, AI has significantly improved mammography screening, particularly in the detection of interval cancers and in patients with dense breast tissue. By utilizing AI algorithms, healthcare professionals can enhance the sensitivity of mammography screening, leading to earlier detection of breast cancer and improved prognosis for patients. This technology has the potential to save lives by detecting cancer at an earlier stage when treatment is most effective.

Overall, the impact of AI on medical imaging cannot be overstated. From the early detection of tumors to the diagnosis of infectious diseases, AI has revolutionized the field of radiology and has significantly improved patient outcomes. By leveraging the power of machine learning algorithms and GANs, healthcare professionals can provide more accurate diagnoses and personalized treatment plans, ultimately leading to better patient care and increased survival rates. As technology continues to advance, the potential for AI in

medical imaging is limitless, offering hope for improved health outcomes for patients around the world. [12, 13].

Current state of AI in radiological imaging for oncology

Deep learning and machine learning in imaging

The hierarchy of Artificial Intelligence involves Machine Learning as its subset, and further under Machine Learning is Deep Learning, which makes use of such specialized architectures as the ANN and CNN to really take advantage of the processings involved in advanced data operations and predictive modeling. Deep Learning is a powerful tool that allows machines to learn from large amounts of data and make complex decisions, leading to significant advancements in various fields such as healthcare, finance, and technology. (Larsen et. al 2022) Fig. 1. Deep Learning has revolutionized the way we approach problem-solving and decision-making, enabling machines to process and analyze massive datasets with incredible speed and accuracy. Its applications in healthcare, for example, have led to breakthroughs in disease diagnosis and treatment, while in finance, it has been instrumental in predicting market trends and optimizing investment strategies. In the field of technology, Deep Learning has paved the way for innovations such as autonomous vehicles and natural language processing,

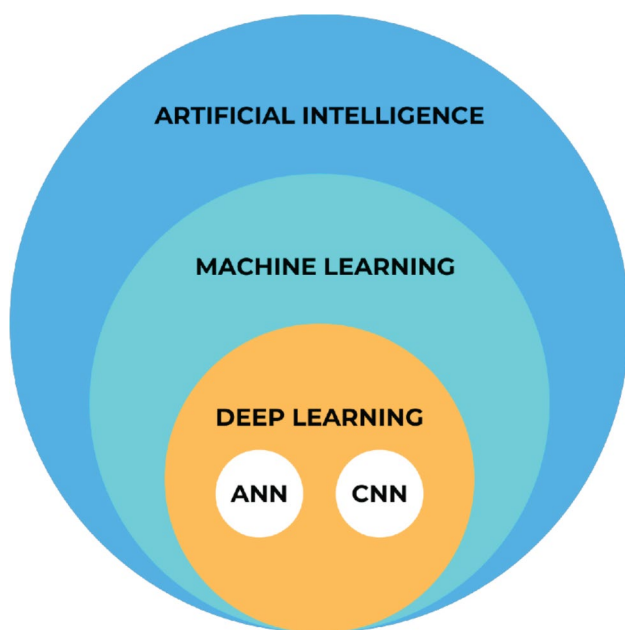


Fig. 1 The hierarchy of Artificial Intelligence involves Machine Learning as its subset, and further under Machine Learning is Deep Learning, which makes use of such specialized architectures as the ANN and CNN to really take advantage of the processings involved in advanced data operations and predictive modeling. (Larsen et. al 2022)

pushing the boundaries of what machines can achieve. As we continue to explore the capabilities of Deep Learning, the possibilities for its impact on society are endless. CNNs provide automatic feature extraction, exceeding previous approaches in breast MRI lesion classification and radiological interpretation [14]. Dermatologists employ CNNs to detect melanoma early [15]. CNNs categorise gastrointestinal anal squamous cell cancer precursors; versatile [1]. CNNs may also evaluate intubation difficulty using face pictures and categorise tympanic membrane conditions [2, 3]. Three-dimensional neural networks automate cervical cancer MRI analysis [2, 4]. AI improves histological evaluation, tumour characterisation, and intraoperative diagnosis, improving malignancy surgery accuracy and efficiency [5–7].

Clinical applications

AI allows for more efficient workflows and shorter reading times, as well as health benefits like early detection, reduced doses and contrasts, improved accuracy, and diagnosis personalization (Yee et al., 2023). This technology has revolutionized the field of medicine by streamlining processes and improving patient outcomes. With AI, healthcare professionals can make more informed decisions and provide personalized care to patients, ultimately leading to better overall health and well-being (Fig. 2). AI classifies anatomical sites with over 99.5% accuracy, relieving radiologists of cognitive effort [16]. AI improves MRI precision by detecting brain scan irregularities and tumour sizes [17]. AI improves PET imaging for lung cancer diagnosis and radiologists' nodule detection [18]. To address radiologist shortages, AI schedules test and prioritises pictures. Lung cancer diagnostic accuracy and efficiency are improved by AI-assisted CT imaging. AI in screening programs improves lung cancer detection and patient outcomes.

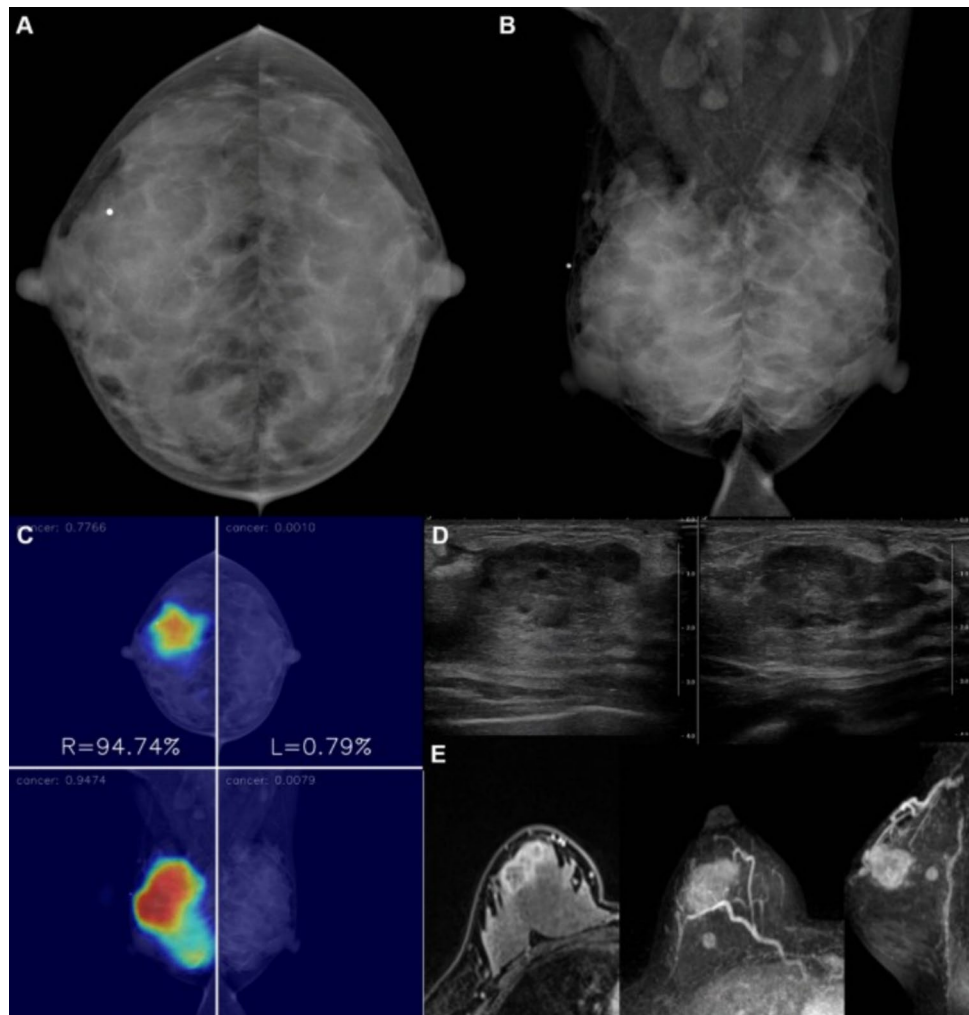
AI has helped discover mammographically occult breast cancer tumours, which are difficult to find on standard radiographs. Kim et al. found that AI-based diagnostic software can detect breast tumours missed by mammography (Fig. 3). Artificial intelligence-identified tumours match breast cancer distribution. This shows that AI can accurately identify clinically relevant tumours, enabling earlier intervention and appropriate treatment [8] Fig. 4.

Deep learning has shown great brain tumour classification accuracy. A deep convolutional neural network to multi-classify brain tumour MRIs with 90.81% accuracy, demonstrating AI's neuro-oncology diagnostic potential. Inception v3 CNN outperformed established NSCLC classification methods for mutation detection and personalised treatment.



Fig. 2 AI allows for more efficient workflows and shorter reading times, as well as health benefits like early detection, reduced doses and contrasts, improved accuracy, and diagnosis personalisation (Yee et al., 2023)

Fig. 3 A 31-year-old lady with right breast invasive ductal cancer. There were no abnormalities on the mammography exam (**A-B**), but AI detected a worrisome focal region in the upper outer quadrant (**C**), which ultrasound (**D**) and MRI (**E**) confirmed as the tumour. A malignancy score of 94.7 was recorded. The core needle biopsy revealed high-grade invasive ductal carcinoma, oestrogen receptor, progesterone receptor, and HER-2-negative. Post-neoadjuvant chemotherapy mastectomy right side revealed invasive ductal cancer (Kim H et al., 2022)



Radiomics improves tumour characterisation by extracting image features using machine learning. AUC of 0.921 in breast cancer diagnosis using radiomics-enhanced MRI. In addition, radiomics can distinguish lung nodules and examine invasive meningiomas before surgery. Radiogenomics enhances cancer detection and treatment.

Advantages of AI in radiological imaging in oncology

Recent advancements in artificial intelligence (AI) have revolutionized oncology imaging, offering a promising future for cancer detection and management. AI algorithms have the ability to detect even the most subtle abnormalities and early signs of malignancies that may have previously

Fig. 4 A 48-year-old woman with right breast invasive ductal cancer. The right axilla had an enlarged lymph node, but the breasts were normal on the mammography exam. AI detected a 44.8 malignancy score spot in the mid-right breast (**B**) where the tumour was confirmed by ultrasonography (**C**) and MRI (**D**). The histopathology demonstrated high-grade invasive ductal carcinoma and negative oestrogen, progesterone, and HER-2 receptors. She had breast-conserving surgery after neoadjuvant chemotherapy and had no residual invasive cancer [18]

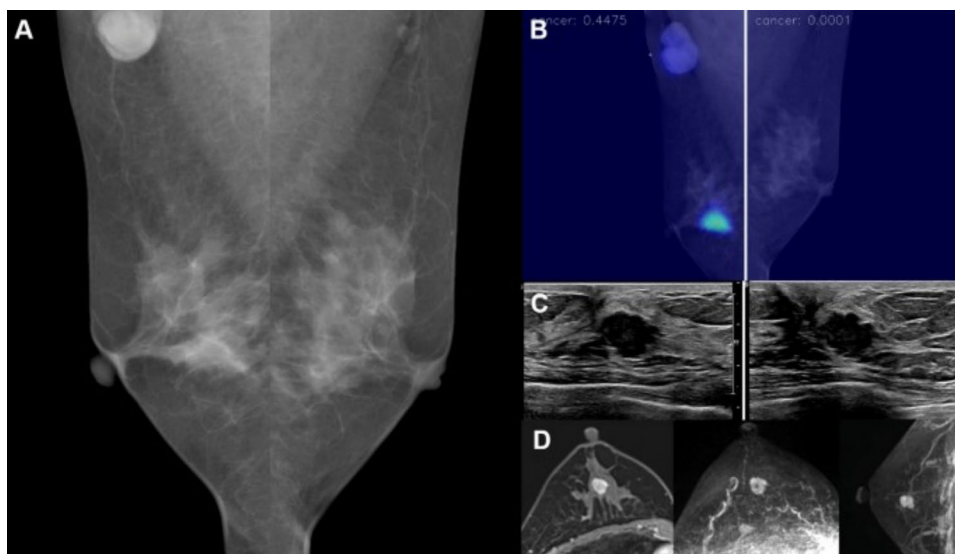


Table 3 Key applications of AI in oncology imaging

Application	Advantage	Example
Early cancer detection	Improved sensitivity and specificity	Detection of interval breast cancers (Oberije et al., 2023)
Tumor segmentation	Precise delineation of tumor boundaries	AI-aided brain tumor segmentation (Kim et al., 2022)
Treatment planning	Personalized therapeutic strategies	Radiomics in breast cancer therapy (Salim et al., 2020)

Table 4 Impact of AI on imaging modalities

Modality	Advantage	Example
Mammography	Enhanced detection of occult lesions	AI in interval breast cancer (Kim et al., 2022)
MRI	Accurate tumor characterization	Multi-classification in brain tumors (Yee et al., 2023)
PET/CT	Detection of distant metastases	Early cervical cancer metastasis (Lin et al., 2012)

gone unnoticed by human radiologists. This early detection capability allows for prompt diagnosis and initiation of treatment, ultimately improving patient outcomes and survival rates. Studies have demonstrated that AI-assisted imaging not only enhances the accuracy and efficiency of cancer diagnosis but also provides valuable insights for personalized treatment strategies. The integration of AI technology in oncology imaging has the potential to transform the field, offering new opportunities for improved patient care and better overall outcomes [12]. AI automates tumour segmentation and picture annotation, improving radiologists' workflow [13]. Breast cancer radiomics uses imaging, genetic, and clinical data to personalise treatment. AI ensures diagnostic consistency, lowering practitioner variability [14]. By increasing lesion detection, tumour characterisation, and

Table 5 Operational barriers in AI deployment

Barrier	Impact	Example
Infrastructure requirements	High costs and resource needs	Computational demands (Yee et al., 2023)
Ethical concerns	Privacy and security risks	Data breaches in cloud storage (Larsen et al., 2022)

metastasis identification, it optimises cancer care in mammography, MRI, and PET/CT (Tables 3 and 4).

Limitations of AI in radiological imaging in oncology

Despite its transformational potential, AI in oncology imaging has limits. Training requires big, high-quality annotated datasets, a major difficulty. AI models may be less generalisable in varied populations due to data heterogeneity and biases [19]. AI models are sometimes "black boxes," making it hard for clinicians to trust or understand their suggestions [20].

Ethical issues also hinder AI deployment. Patient data privacy, informed consent, and regulatory approval are complicated. The FDA requires substantial validation to approve AI-based medical solutions, slowing their implementation [4]. AI integration into existing systems requires expensive infrastructure, which might strain healthcare practitioners, especially in resource-limited situations [1] Table 5.

Efforts to address these barriers, including interdisciplinary collaboration and advancements in AI technology, are vital for realizing its full potential in oncology imaging.

Integrating AI in oncology

Data quality and availability

AI medical imaging faces dataset quality, quantity, and diversity issues. AI models need well-annotated datasets, yet noise, artefacts, and inconsistencies cause problems. Data for deep learning models is limited by privacy and annotation costs. Wang found homogeneous datasets impair generalisability, since single-center radiomics models failed external validation [21]. In addition, various imaging conditions for dependability and self-supervised learning, like contrastive learning, uses huge, unlabelled datasets to overcome data restrictions.

Regulatory and ethical concerns

References to established AI governance frameworks, such as the EU AI Act and the FDA Guidelines on Adaptive Algorithms, play a crucial role in shaping the responsible development and implementation of AI technologies. The EU AI Act, for example, establishes requirements for AI systems to be transparent, understandable, and accountable, with specific provisions for high-risk AI applications. Meanwhile, the FDA Guidelines on Adaptive Algorithms provide recommendations for the development and validation of AI algorithms used in medical devices, ensuring their safety and effectiveness. [16].

These frameworks not only provide a roadmap for organizations to follow in developing AI systems, but also serve as a benchmark for ethical and responsible AI practices. By integrating these guidelines into their AI development processes, organizations can demonstrate their commitment to AI ethical principles and build trust with stakeholders and the public. This, in turn, can lead to greater adoption of AI technologies across various sectors, as concerns about the ethical implications of AI are addressed through adherence to established governance frameworks. Ultimately, the use of these frameworks can help ensure that AI technologies are developed and deployed in ways that benefit society while minimizing potential risks and harms.

AI medical imaging algorithms must be validated before use. AI's early acceptance is highlighted by Yee *et. al.*, 2023 medical innovation adoption cycle [20]. Meeting clinical standards requires developer, clinician, and regulator engagement in workflow integration. Informed permission for patient data use raises ethical considerations. In addition, the data usage and withdrawal options transparent to build patient trust in AI. Integrating AI into healthcare safely requires standardisation, validation, and ethics.

AI in healthcare concerns interpretability, security, and moral issues. AI enhances diagnostic accuracy, but its lack

of transparency limits clinical usage, requiring interpretable models. In addition, the ethical issues like as bias and trust must be addressed and the legal approaches to balance innovation and patient safety [22–26]. The Canadian Association of Radiologists publishes privacy, confidentiality, and AI application ethics to protect patients [4, 5].

Clinical adoption and trust

AI developers must ensure algorithms are technically and therapeutically relevant. Technology like the BodyGuardian Remote Monitoring System and clinician collaboration for practical applications [5]. AI-enhanced imaging analytics research emphasises workflow integration through clinician-developer cooperation, therefore rigorous validation and standardisation are essential [27]. Regulatory agencies like the FDA must be engaged to assure safety and efficacy. In addition, multi-stakeholder collaboration in ethical AI implementation across development and deployment [5, 9].

Future perspectives

Advances in AI models

AI enhances oncology by analysing large datasets from diverse sources. AI can improve treatment predictions and personalized care [6]. AI-driven predictive analytics refine therapy selection. The technology of artificial intelligence is revolutionizing the field of personalized medicine, allowing doctors to tailor treatments based on the specific genetic and biological characteristics of each patient. In particular, the implementation of the FAIR principles (Findable, Accessible, Interoperable, Reusable) and federated learning is significantly improving the effectiveness and efficiency of personalized medicine.

The FAIR principles ensure that the data used to train artificial intelligence algorithms are easily accessible, interoperable, and reusable. This allows researchers to access a wide range of data from different sources and use it to improve the accuracy of predictive models. Additionally, federated learning allows artificial intelligence models to be trained on data distributed across different healthcare institutions, without the need to directly share sensitive patient data. This approach ensures data privacy and security while harnessing the diversity and scale of data to improve model accuracy.

However, despite the numerous advantages offered by the combination of FAIR principles and federated learning in personalized medicine, there are also challenges and issues to address. For example, it is essential to ensure the quality and integrity of data used to train artificial intelligence

models to avoid biases and errors in predictions. Additionally, it is important to develop ethical standards and guidelines to ensure the respect of privacy and patient rights in the treatment of their health data.

In conclusion, the implementation of FAIR principles and federated learning represents a significant step forward in promoting personalized medicine through artificial intelligence. However, it is necessary to address the challenges and issues associated with this technology to ensure that the benefits derived from it are maximized and that ethical and legal principles are respected in the treatment of patient health data. [8]. Collaboration between AI developers and clinicians, as Alam suggests, ensures tailored models [28]. AI's role in personalized plasma medicine for individualized treatment strategies.

AI in radiology workflow automation

Deep learning-based medical picture annotation technologies like RIL-Contour reduce manual effort. FDA-approved AI technologies like Arterys Inc.'s connect with PACS systems to improve image interpretation and diagnostic speed and accuracy. Annotation Web simplifies ultrasound picture annotation but raises data security risks. AI-assisted diagnostics enhance teledermatology accuracy, enabling doctors prioritise urgent cases [19].

AI in predictive analytics and prognosis

By analysing imaging data, AI can diagnose metastases early. Motohashi's deep learning model diagnoses spinal metastases in CT scans early. Kim et al. demonstrated enhanced sensitivity to anomalies in mammography diagnosis of early-stage invasive carcinoma with AI [8]. AI integrates imaging and clinical data to improve illness monitoring. In addition, it also highlights its importance in predicting chemotherapy response with mpMRI [6]. AI has the capacity to predict metastasis-related hazards including ischaemic stroke, improving patient treatment and minimising complications [29, 30] Table 6.

Conclusion

AI is improving oncology imaging accuracy and efficiency for cancer diagnosis and management. Through AI-powered deep learning models, radiomics, and multimodal imaging, cancer can be detected early and treated. These devices help healthcare providers intervene more precisely and timely. It may improve diagnosis accuracy but also reduces time and helps organise treatment. Forward-looking AI promises a personalised, efficient integrated system. It will form the

Table 6 Challenges in AI implementation

Challenge	Impact	Example
Data quality and diversity	Limited generalizability	Bias in lung cancer imaging (Liu et al., 2023)
Interpretability	Reduced clinician trust	Complex decision-making models (Yee et al., 2023)

basis for proactive therapy using genetics, imaging, and clinical data. Although it is difficult and requires quality data, regulatory, and ethical issues, collaboration between developers, clinicians, and politicians will be beneficial. Further study and joint efforts can overcome such obstacles and turn these potentials into health improvements. AI-enabled oncology imaging will revolutionise cancer detection, management, and treatment. This fight against sickness has made the largest progress.

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Declarations

Conflict of interest The authors have no conflicts of interest to be disclosed.

Ethical approval Not applicable.

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