National Conference on Behavioural Economics and Intelligent Decision Systems for Climate Change and Sustainable Development
International Journal of Healthcare Education & Medical Informatics
Volume 13, Issue 1&2 - 2026

Review Article

Advances in Artificial Intelligence for Lung Cancer Detection: A Review of Imaging and Computational Approaches

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DOI: https://doi.org/10.24321/2455.9199.202601

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How to cite this article:
Kaur P, Kaur P, Kaur K, Kaur A. Advances in Artificial Intelligence for Lung Cancer Detection: A Review of Imaging and Computational Approaches. J. HealthCare Edu. & Med. Inform. 2026;13(1&2):115-120.

Date of Submission: 2025-10-04
Date of Acceptance: 2025-10-28

ABSTRACT

Lung cancer is the leading cause of cancer-related deaths worldwide, and early detection significantly improves survival. Artificial intelligence (AI), particularly deep learning and convolutional neural networks (CNNs), has emerged as a powerful tool in thoracic imaging and diagnostics. Recent research has demonstrated that AI is capable of accurately detecting, categorising, and segmenting lung nodules on chest radiographs, low-dose CT (LDCT), and histology, often matching or outperforming radiologists in this regard. AI also makes it easier to predict histological subtypes, characterise non-invasive tumours, and integrate prognostic information with clinical data. However, problems like limited dataset generalisability, high false-positive rates, and restricted clinical application still persist. This study examines recent findings demonstrating AI's potential to transform lung cancer detection while addressing the challenges to real-world implementation.

Keywords: Artificial Intelligence; Deep Learning; Machine Learning; Abbreviations Computed Tomography (CT), Low-Dose Computed Tomography (LDCT), Computer-Aided Diagnosis (CADx), Area-Under-the-Curve (AUC), Convolutional Neural Networks (CNNs)

Introduction

Lung cancer accounts for approximately 18% of all cancer-related deaths worldwide, highlighting the urgent need for improved detection strategies.[1] Low-dose computed tomography (LDCT) is the current gold standard for screening high-risk populations, but its effectiveness is limited by inter-observer variability, missed nodules, and high false-positive rates. Artificial intelligence (AI), particularly deep learning, has emerged as a promising approach in thoracic imaging, enhancing diagnostic accuracy and automating labour-intensive tasks. Early AI efforts focused on computer-aided diagnosis (CADx) and detection (CADe) systems using rule-based algorithms and handcrafted features, which often showed limited clinical integration and accuracy. The advent of convolutional neural networks (CNNs) has significantly improved lung nodule detection, segmentation, and classification by enabling end-to-end learning from raw imaging data.[2] CNN-based models outperform manual segmentation and accurately distinguish benign from malignant nodules, achieving high area-under-the-curve (AUC) values. AI applications have expanded to histopathology and genomics, with multimodal models integrating imaging and molecular data to predict tumour subtypes and patient prognosis.[3]

In the current healthcare landscape, where lung cancer remains one of the leading causes of mortality and healthcare systems are increasingly burdened, the relevance of AI is further heightened. Its ability to accelerate diagnosis, support clinical decision-making, and enable cost-effective screening especially in resource-limited settings emphasises its growing significance in modern medical practice.

Despite these advances, clinical adoption is limited due to the "black-box" nature of deep learning, poor generalisability, and insufficient prospective validation. Overcoming these challenges is crucial to harness AI as a reliable tool for early detection, precise diagnosis, and personalised lung cancer management.

The Graphical representation illustrates how lung nodules and cancer are examined using medical imaging techniques such as a CT scan and chest X-ray. The three steps of detection, segmentation, and classification are highlighted as depicted in Figure 1. It also demonstrates how AI can forecast the prognosis, mutations, and subtypes of cancer.

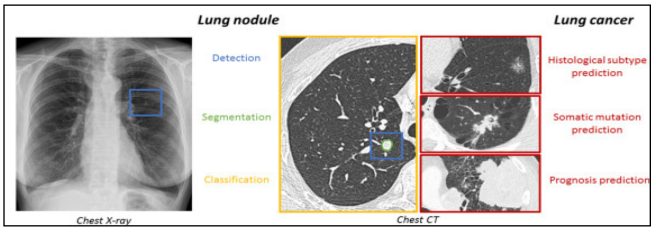

Figure 1.Graphical representation of deep learning applications for lung nodule and lung cancer in chest imaging[21]

Conventional Imaging and Diagnostic Approaches in Lung Cancer

Traditional imaging techniques continue to be essential for diagnosing and staging lung cancer. Chest radiography (CXR) is frequently the first imaging method; however, its sensitivity is restricted, particularly for small or early lesions. Computed Tomography (CT), especially high-resolution CT (HRCT), provides enhanced spatial resolution, facilitating in-depth visualisation of pulmonary nodules, mediastinal structures, and possible metastases. CT plays a crucial role in evaluating tumour size, position, and lymph node involvement, contributing to precise staging. Additionally, low-dose CT (LDCT) screening has shown effectiveness in early identification, resulting in enhanced survival rates among high-risk groups.[4] Positron Emission Tomography (PET), frequently paired with CT (PET/CT), offers functional imaging by identifying metabolic activity. Fluorodeoxyglucose (FDG) PET/CT is especially useful for differentiating between malignant and benign lesions, evaluating nodal involvement, and detecting distant metastases. Research indicates that PET/CT may provide greater sensitivity and specificity than CT by itself in specific situations.[5] Tissue biopsy continues to be the benchmark for conclusive diagnosis, enabling histopathological assessment and molecular analysis. Techniques consist of bronchoscopy, transthoracic needle aspiration, and ultrasound-guided biopsy via the endobronchial approach. These processes are essential for identifying tumour histology and directing targeted treatments.

Artificial Intelligence in Lung Cancer

Artificial Intelligence (AI) is revolutionising lung cancer care by improving early detection, diagnosis, and treatment strategies. AI algorithms, especially deep learning models, have shown great precision in examining medical imaging data, including low-dose computed tomography (LDCT), chest X-rays, and positron emission tomography (PET) scans. These models support radiologists in detecting and defining pulmonary nodules, resulting in enhanced screening results and earlier diagnoses.[6] In addition to imaging, AI combines clinical and genomic information to forecast treatment outcomes and patient prognosis. Models of machine learning examine biomarkers and genetic alterations, assisting in choosing personalised therapies and predicting recurrence risks.[7]

Conventional vs. AI-Based Approaches in Lung Cancer Detection

Radiologists rely on conventional imaging, which offers moderate sensitivity, limited early detection, and minimal predictive power. AI-based approaches enhance sensitivity, staging, and early detection by integrating imaging with clinical and molecular data Table 1. These approaches predict prognosis and treatment response but face challenges of data requirements, interpretability, ethics, and regulatory approval.

Table 1.Comparison of Conventional vs. AI-Based Approaches in Lung Cancer Detection

Feature	Conventional Imaging & Diagnostics	AI-Based Approaches
Imaging Modality	Chest X-ray, CT, HRCT, PET/CT	Chest X-ray, CT, PET/CT, LDCT with AI analysis[9,6]
Detection Accuracy	Moderate sensitivity, especially for small nodules; depends on radiologist experience	High sensitivity and specificity; can detect subtle nodules missed by human eyes[6,7]

ISSN: 2455-9199
DOI: https://doi.org/10.24321/2455.9199.202601

Integration of Clinical Data	Primarily imaging and lab tests	Combines imaging, genomics, biomarkers, and clinical parameters for prediction[7,5]
Early Detection	Limited for small or early-stage tumors; often detected late	Enhanced early detection through deep learning models and radiomics[9,10]
Staging Accuracy	Moderate; depends on imaging modality and radiologist expertise	Improved staging and metastasis detection using AI-assisted imaging analysis[6,10]
Predictive Capability	Minimal predictive power; mainly Descriptive	Predicts prognosis, treatment response, recurrence risk, and patient outcomes[6,7]
Limitations	Inter-observer variability; human fatigue; limited in subtle lesions	Requires large labeled datasets; black-box nature; regulatory & ethical issues[7,5]
Clinical Adoption	Widely used and standard of care	Increasingly integrated; FDA-approved tools emerging[6,10]

Computational and Data-Driven Approaches in Lung Cancer

Alongside traditional imaging, computational and data-driven methods are becoming more and more important in the study, diagnosis, and treatment of lung cancer. These methods use statistical models, deep learning (DL), and machine learning (ML) to analyse huge, diverse datasets, including genomic, imaging, transcriptomic, proteomic, and clinical data. AI can spot tiny patterns that are frequently missed by human observers by combining multi-modal data, which allows for earlier diagnosis and more accurate risk categorisation.[11]

Lung cancer frequently uses radiomics, a computer technique that derives quantitative characteristics from medical imaging. Radiomics makes tumour characterisation, growth prediction, and therapy response evaluation easier by transforming pictures into high-dimensional data. These properties enable prognosis prediction and predictive modelling when combined with machine learning methods like support vector machines, random forests, and neural networks.[12]

Data-driven methods employ molecular and genomic analysis in addition to imaging to direct customised treatment. AI models use gene alterations in EGFR, KRAS, and ALK to forecast recurrence risk, immunotherapy effectiveness, and response to targeted treatments. In order to maximise resource allocation, population-level predictive modelling also aids in identifying high-risk individuals for screening programmes. Predictive analytics is further improved by combining real-world clinical data with electronic health records (EHR). Clinical decision-making is supported by models that have been trained on sizeable datasets to detect prognostic markers, therapy response patterns, and adverse event risks.[13]

The requirement for sizable, varied, high-quality datasets, model interpretability, and regulatory approvals are still obstacles in spite of these advancements. Nevertheless, there is a lot of potential for developing customised therapy, enhancing early detection, and improving lung cancer treatment through computational and data-driven methods.

AI-Based Imaging Approaches and Clinical Application & Validation

By facilitating automated tumour detection, characterisation, and staging, artificial intelligence (AI) has greatly improved lung cancer imaging. To detect lung nodules with high sensitivity, deep learning models—in particular, convolutional neural networks (CNNs)—analyse CT, low-dose CT (LDCT), chest X-rays, and PET/CT images.[8] By identifying minute morphological and textural patterns, radiomics further converts imaging data into quantitative variables that aid in tumour characterisations and risk assessment.[14] By combining information from multiple imaging modalities, multi-modal AI systems increase diagnostic precision and lower false positive rates. Table 2.

AI is being used in lung cancer clinical settings for both screening and diagnostic procedures. AI-assisted LDCT screening has shown increased early detection rates and decreased missed lesions in high-risk patients. Additionally, AI models are being verified for therapy response prediction, metastatic identification, and staging. The FDA's approval and other regulatory approvals have made it possible to incorporate AI tools into standard clinical practice. AI can match or surpass human performance in nodule detection

ISSN: 2455-9199
DOI: https://doi.org/10.24321/2455.9199.202601

and classification, while also cutting down on interpretation time, according to validation studies comparing AI performance with that of seasoned radiologists.[15] There are still issues with data uniformity, model interpretability, and clinical workflow integration Table 3.

Challenges and Limitations of AI in Lung Cancer

Despite impressive progress, there are still a number of obstacles to overcome before AI can be used clinically to treat lung cancer. To train effective models, one significant drawback is the need for large, high-quality, and annotated datasets, which are frequently hard to come by because of privacy laws and variations in imaging procedures.[16] Models trained on certain demographics or imaging systems may not perform well in other clinical situations, raising concerns about algorithm generalisability. Furthermore, AI systems frequently lack interpretability and are black boxes, which undermine regulatory adoption and clinical trust. Upgrades to the infrastructure and staff training are necessary for the often difficult integration into current clinical workflows. Missed diagnoses or needless treatments could result from false positives and negatives, particularly in small or early-stage nodules.[17] The adoption process is further complicated by ethical and legal concerns, such as bias, accountability, and data privacy. Resolving these issues is essential to converting AI research into widely accepted, secure, and useful therapeutic applications.

Future Directions of AI in Lung Cancer

Emerging AI approaches focus on explainability, multimodal integration, and cloud platforms to improve trust, diagnosis, personalisation, and accessibility, as in Table 4. Clinical and research opportunities emphasise population screening, personalised medicine, and continuous learning to enhance early detection, optimise treatments, and ensure adaptability, as in Table 5. Together, they aim to establish AI as a reliable, equitable, and evolving tool in lung cancer care.

Table 2.AI-Based Imaging Approaches in Lung Cancer

Approach	Imaging Modality	Key Function	Advantages
Deep Learning (CNN)	CT, LDCT, X-ray, PET/CT	Nodule detection & classification	High accuracy; automated; rapid analysis
Radiomics	CT, PET/CT	Feature extraction; tumor characterization	Quantitative, captures subtle patterns
Multi-Modal AI	CT + PET/CT + X-ray	Integrative diagnosis	Improves specificity; reduces false positives

Table 3.Clinical Application & Validation

Application	Clinical Utility	Validation Outcomes
Screening	High-risk population LDCT	Improved early detection; reduced missed lesions
Staging & Metastasis	CT + PET/CT	Accurate staging; aids therapy planning
Treatment Response Prediction	Imaging + biomarkers	Predicts chemotherapy/immunotherapy efficacy

Table 4.Emerging AI Approaches

Future Approach	Purpose	Expected Benefit
Explainable AI (XAI)	Improve interpretability	Increase clinician trust; regulatory acceptance[18]
Multi-Modal AI	Integrate imaging, genomics, and biomarkers	Enhanced diagnosis, risk prediction, and personalized therapy
Cloud-Based AI Platforms	Remote analysis and screening	Accessibility for low-resource settings; real-time analysis[18,19]

ISSN: 2455-9199
DOI: https://doi.org/10.24321/2455.9199.202601

Table 5.Clinical and Research Opportunities

Area	Objective	Expected Outcome
Population Screening	Identify high-risk individuals	Early detection; optimized resource allocation
Personalized Medicine	Predict treatment response	Tailored therapy selection; improved outcomes[20]
Continuous Learning Systems	Update models with real-world data	Improved performance; adaptability to new populations

Abbreviations

Computed Tomography (CT), Low-Dose Computed Tomography (LDCT), Computer-Aided Diagnosis (CADx), Area-Under-the-Curve (AUC), Convolutional Neural, Networks (CNNs)

Conclusion

The detection, diagnosis, and treatment of lung cancer are being profoundly changed by artificial intelligence (AI), which increases workflow efficiency, sensitivity, and specificity. AI-driven models facilitate the integration of multi-modal data, including imaging, genomics, and clinical biomarkers, as well as the early detection of lung nodules and precise tumour characterisation. A move toward data-driven, individualised lung cancer care is indicated by these important discoveries, which can improve treatment results and shorten diagnostic wait times. These developments have significant ramifications since AI fosters precision medicine, aids physicians in making decisions, and lowers human error in radiological interpretation. Nonetheless, a number of obstacles still exist, such as the requirement for superior annotated datasets, worries about the interpretability of the models, regulatory approval, and smooth integration into clinical procedures. Future advancements, including multimodal integration, cloud-based platforms, and explainable AI, should improve the clinical applicability, dependability, and transparency of AI systems. Clinical professionals, data scientists, regulatory bodies, and healthcare organisations must continue to work together to guarantee widespread adoption. All things considered, AI has great potential to transform the treatment of lung cancer by maximising the use of available resources, increasing the effectiveness of diagnostics, and improving patient outcomes in the rapidly developing field of oncology.

Source of Funding: The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Acknowledgement: I would like to express my sincere gratitude to the Department of Computer Engineering & Technology, Guru Nanak Dev University, Amritsar, for providing the academic resources and support that made this work possible. I am grateful to Dr. Prabhpreet Kaur, for her invaluable guidance, encouragement, constructive feedback, and to Dr. Kiranbir Kaur and Dr. Amandeep Kaur for their insightful discussions and encouragement during this work. Furthermore, I gratefully acknowledge the contributions of researchers and practitioners in the field of artificial intelligence and medical imaging, whose work provided the foundation and inspiration for this review. I wish to thank my co-authors for their collaboration and continuous support in completing this research successfully.

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ISSN: 2455-9199
DOI: https://doi.org/10.24321/2455.9199.202601