ISSN (e): 2250 – 3005 || Volume, 15 || Issue, 6|| June – 2025 ||
International Journal of Computational Engineering Research (IJCER)

Artificial Intelligence in Lung Cancer Diagnosis and Prognosis: A Review of Hybrid Models, Multimodal Integration, and Future Directions

PRIYANKABEN VASHI[a], Anurag Yadav[b]
[a,b] Assistant Professor, SOE P.P. Savani University, NH 8, GETCO, Dhamdod, Kosamba, 394125, India

Abstract: *Lung cancer remains a leading cause of cancer-related mortality worldwide. The integration of artificial intelligence (AI), particularly deep learning and hybrid neural networks, offers transformative potential in improving early detection, diagnosis, and prognosis of lung cancer. This review provides a comprehensive analysis of the current advancements in AI applications in lung cancer, focusing on hybrid neural network models, multimodal data fusion, uncertainty quantification, genetic mutation prediction, and relapse forecasting. We also explore the role of cost-effective AI models and the growing field of explainable AI (XAI). Our findings suggest that while significant progress has been made, challenges remain in standardization, clinical integration, and interpretability. The paper concludes by highlighting key areas for future research and development.*

Date of Submission: 15-06-2025 Date of acceptance: 30-06-2025

I. Introduction:

Lung cancer remains one of the leading causes of cancer-related deaths worldwide and is recognized for its aggressive nature and typically late-stage diagnosis. Conventional diagnostic techniques, such as tissue biopsies, bronchoscopy, and radiological image assessments (CT, PET, or X-ray scans), although widely used, are not without limitations. These methods can be invasive, costly, time-intensive, and sometimes yield inconsistent results due to human error or varying image interpretation.In response to these challenges, the integration of Artificial Intelligence (AI) and machine learning (ML) into medical diagnostics has gained significant attention. AI offers the potential to revolutionize lung cancer detection by enabling early-stage diagnosis through automated, non-invasive, and high-precision systems. Among the many AI techniques explored, hybrid neural networks—particularly those combining Convolutional Neural Networks (CNNs) with other deep learning models—have shown remarkable performance in processing and interpreting complex medical data. These models are capable of extracting and learning intricate features from radiological images, histopathological slides, genomic data, and electronic health records.

Furthermore, the use of **multimodal data integration**, where multiple sources of patient information (e.g., imaging, clinical, genetic) are fused using deep learning architectures, provides a more holistic and accurate diagnostic framework. This review comprehensively synthesizes recent research efforts in AI-based lung cancer diagnosis, with a special emphasis on **hybrid neural networks**, **multimodal AI models**, and their **clinical applicability**. We aim to highlight not only the technical advancements and architectural innovations but also the real-world implications of these systems in improving diagnostic workflows, reducing the burden on healthcare professionals, and ultimately contributing to better patient outcomes..

1. AI Techniques for Lung Cancer Detection

I. **Deep Learning and Convolutional Neural Networks (CNNs):** CNNs have demonstrated remarkable success in image-based diagnosis using CT and PET scans. 3D-CNNs, in particular, are adept at capturing spatial features relevant to tumor identification by analyzing volumetric data, which allows for improved tumor localization and characterization.

II. **Hybrid Neural Network Architectures:** Combining CNNs with other architectures, such as recurrent neural networks (RNNs) or attention mechanisms, enhances model capacity to learn both spatial and temporal dependencies. The Cancer Cell Detection using Hybrid Neural Network (CCDC-HNN) is an example of a model that integrates multiple deep learning layers to improve feature extraction and classification accuracy.

2. Multimodal Data Fusion in Diagnosis

I. **Integration of Imaging, Genomics, and Clinical Data:** Multimodal Fusion Deep Neural Networks (MFDNNs) allow the convergence of diverse datasets, including radiological images, gene expression profiles, and patient demographics. This integration enhances diagnostic precision and helps uncover hidden patterns that may not be visible from a single data source.

II. **Case Studies and Performance Metrics:** Empirical studies have shown improved classification accuracy, sensitivity, and specificity when multimodal data is utilized. Such models also show promise in subtyping tumors and predicting therapy response.

3. Uncertainty Quantification in AI Models

I. **Importance of Model Confidence in Clinical Settings:** In high-stakes medical applications, understanding how confident an AI model is in its prediction is crucial. Uncertainty quantification ensures that models flag ambiguous cases for human review, thereby reducing the risk of misdiagnosis.

II. **Bayesian Deep Learning and Monte Carlo Dropout:** These techniques allow the model to estimate the variability in its outputs. Bayesian methods provide probabilistic interpretations of predictions, while Monte Carlo Dropout simulates ensemble behaviors to gauge uncertainty.

4. Predicting Genetic Mutations from Imaging

I. **Radiomics and Feature Extraction:** Radiomics involves extracting high-dimensional features from medical images that reflect tumor phenotype. AI algorithms can associate these imaging biomarkers with genetic mutations like EGFR, ALK, KRAS, and BRAF.

II. **Clinical Relevance and Validation:** Predicting mutations non-invasively from imaging data helps avoid tissue biopsy in some patients. Although results are promising, large-scale clinical validation and regulatory approval are necessary for real-world deployment.

5. Relapse Prediction in NSCLC

I. **Role of Aneuploidy and Genomic Scores:** Aneuploidy scores derived from genomic instability measures can be input into AI models to predict the likelihood of cancer recurrence. This helps in stratifying patients for personalized follow-up.

II. **Personalized Prognosis:** By using patient-specific data, AI models can predict the timeline and probability of relapse, enabling oncologists to devise personalized surveillance and treatment plans.

6. Cost-Effective AI Solutions

I. **Lightweight Models for Resource-Limited Settings:** Developing AI models with fewer computational demands is essential for use in rural and under-resourced medical centers. Techniques such as model pruning, quantization, and mobile deployment support this goal.

II. **Democratizing Access to Diagnostic Tools:** AI tools can assist less experienced practitioners and enable remote diagnostics through telemedicine platforms, contributing to equitable healthcare delivery.

7. Explainable AI in Lung Cancer Diagnostics

I. **Model Interpretability Tools:** Explainable AI techniques like Gradient-weighted Class Activation Mapping (Grad-CAM) and SHAP (SHapley Additive exPlanations) help visualize which parts of an image influenced a prediction. This provides transparency into model decisions.

II. **Building Clinician Trust:** Interpretability bridges the gap between black-box AI models and medical professionals, enhancing confidence and enabling collaborative decision-making.

8. Challenges and Future Directions

I. **Data Privacy and Standardization:** Medical data often varies across institutions in terms of format, resolution, and labeling, hindering model generalization. Privacy regulations like HIPAA and GDPR add complexity to data sharing.

II. **Clinical Integration:** Embedding AI systems into hospital workflows requires robust validation, user-friendly interfaces, and continuous model monitoring.

III. **Future Research Avenues:** Promising directions include federated learning (collaborative training without data sharing), real-time model inference, and large-scale multi-institutional validation studies.

III. Conclusion

AI has shown tremendous potential in revolutionizing lung cancer diagnosis and prognosis. From deep neural networks to uncertainty-aware models and multimodal fusion techniques, the AI toolkit is rapidly evolving. While existing studies highlight promising results, translational challenges must be addressed to realize full clinical utility. Future research should focus on model robustness, ethical deployment, and cross-institutional collaborations to pave the way for AI-driven precision oncology.

References

[1]. Wankhade, Shalini,“A novel hybrid deep learning method for early detection of lung cancer using neural networks”,Healthcare Analytics,2023
[2]. Imranul Kabir Chowdhury, “Advancements in Early Detection of Lung Cancer in Public Health: A Comprehensive Study Utilizing Machine Learning Algorithms and Predictive Models”, Journal of Computer Science and Technology Studies,2024
[3]. Üzülmez, Sema,“Early diagnosis of lung cancer using deep learning and uncertainty measures”, Journal of the Faculty of Engineering and Architecture of Gazi University,2024
[4]. Mohan,“Machine learning estimated probability of relapse in early-stage non-small-cell lung cancer patients with aneuploidy imputation scores and knowledge graph embeddings”, ELSEVIER,2024
[5]. Chen,“Accuracy of machine learning in preoperative identification of genetic mutation status in lung cancer: A systematic review and meta-analysis”, Radiotherapy and Oncology,2024
[6]. Sangeetha,“An enhanced multimodal fusion deep learning neural network for lung cancer classification”, ELSEVIER,2024
[7]. Quanyang,“Artificial intelligence in lung cancer screening: Detection, classification, prediction, and prognosis” Cancer Medicine,2024
[8]. Javed,“Deep learning for lungs cancer detection: a review”, BIOMED INFORMETICS,2024
[9]. Mohamed,“Enhancing Lung Cancer Classification and Prediction With Deep Learning and Multi-Omics Data”, IEEE,2024
[10]. Wang,“A systematic review of risk prediction model of venous thromboembolism for patients with lung cancer”,WILEY,2024
[11]. “Machine Learning for Early Discrimination Between Lung Cancer and Benign Nodules Using Routine Clinical and Laboratory Data”, SpringerLink,2024