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The Application Value of Artificial Intelligence in Pulmonary Nodule Detection and Benign-Malignant Classification

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Abstract:

Artificial intelligence demonstrates significant value in detecting pulmonary nodules and determining whether they are benign or malignant. With the ever-growing applications of low-dose CT screening, the detection speed of pulmonary nodules has increased substantially. However, manual diagnosis faces challenges including missed detections and inconsistent interpretations among different radiologists. This article provides a systematic review of artificial intelligence (AI) applications in lung cancer screening. It focuses on the automated identification, segmentation, and diagnostic classification of pulmonary nodules. We specifically examine the performance of deep learning models like CNN and U-Net, comparing results from multiple clinical studies. Research findings indicate that AI achieves high sensitivity of up to 98.98% in nodule detection and reaches AUC values between 0.88 and 0.936 in benign-malignant classification. These results are comparable to, and in some cases exceed, the performance of experienced radiologist teams. Additionally, AI shows potential in predicting pathological subtypes and improves diagnostic accuracy through multi-modal integration. By providing quantitative feature analysis and model integration, AI technology offers more objective and consistent diagnostic support. Its high sensitivity and substantial value as a diagnostic aid suggest that AI will likely become an essential component of standard clinical workflows in the near future.

Keywords: Artificial Intelligence, Pulmonary Nodule, Deep Learning, Computer-Aided Diagnosis, Benign-Malignant Classification.

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1. Introduction

Since the Dartmouth Conference in 1956, artificial intelligence (AI) has experienced periods of significant progress and setbacks. Researchers in the 1960s were optimistic about achieving human-level AI, but limitations in algorithms and computing power hindered development. The field faced two major challenges between the 1970s and 1990s due to technical bottlenecks and funding issues. A major turning point occurred in 1997, when IBM's Deep Blue triumphed over world chess champion Garry Kasparov—a milestone that announced AI's arrival into real-world use [1]. In modern medical imaging, the exponential growth of global data volume has been growing at over 30% annually, substantially increasing radiologists' workload [2]. This has led to more missed diagnoses of ground-glass nodules (GGNs), which are considered key indicators of early lung cancer and inconsistent diagnoses among physicians with different experience levels. To address these challenges, advanced deep learning models like 3D U-Net and Hybrid Convolutional Neural Network (CNN) now help address these challenges by reducing errors from image noise and low contrast. These sophisticated AI systems can automatically detect and segment pulmonary nodules while identifying subtle features invisible to the human eye. Large-scale clinical studies demonstrate that AI-assisted CT reconstruction improves GGN detection rates from 80.8% to 90.7%, providing stronger support for early lung cancer screening [3]. Furthermore, AI models also show high sensitivity in distinguishing benign from malignant nodules, with results that align closely with pathological findings. Beyond detection and classification, emerging evidence suggests AI systems can also predict pathological subtypes and patient prognosis through radiomic feature analysis. This article reviews the latest applications of AI in pulmonary nodule detection and classification, examines how it enhances diagnostic accuracy and efficiency, and discusses current challenges and future directions.

2. Application of AI in Pulmonary Nodule Segmentation and Detection

The advancement of AI in medical imaging has significantly raised the accuracy and efficiency of early lung cancer screening through enhanced segmentation and detection of pulmonary nodules. As pulmonary nodules can serve as precursors to cancer, accurate identification and characterization by clinicians are crucial for patient outcomes. Traditional detection methods, which rely on radiologists' subjective visual assessment, often lead to issues such as missed diagnoses and low efficiency. In contrast, AI utilizes deep learning and advanced algorithms like convolutional neural networks (CNNs) to enable automated detection, classification and segmentation of pulmonary nodules as benign or malignant.

In the domain of nodule detection, AI demonstrates exceptionally high sensitivity, particularly in identifying small nodules. A study involving 113 patients showed that an AI-based software achieved a detection rate of 98.98% for true positive nodules, significantly surpassing manual interpretation while substantially reducing the rate of missed diagnoses. However, the relatively higher false-positive rate of AI suggests there is room for improvement in specificity, as structures such as blood vessels or pleural thickening are occasionally misclassified as nodules [4]. In an ultra-low-dose CT (ultra-LDCT) baseline screening study, AI-based interpretation resulted in only 8 false-negative misclassifications (NM) among 283 participants, outperforming most experienced radiologists and demonstrating a high negative predictive value (NPV = 0.95) [5]. Another study further confirmed strong agreement between AI and experts in detecting pulmonary nodules on low-dose CT (LDCT), with a Cohen's kappa number of 0.846, sensitivity of 92.9%, and specificity of 96% [6]. The AI system performed comparably to experts in ruling out negative cases. Additionally, for nodules smaller than 5 mm and those measuring 5–10 mm, the AI system achieved detection rates of 98.69% and 100%, greatly exceeding human performance rates of 60.59% and 80.25%, respectively [4]. The ability of AI to rapidly process large volumes of CT images also markedly reduces the workload for physicians.

In nodule segmentation tasks, AI models such as U-Net have exhibited excellent performance. Compared to traditional filtering methods, U-Net attained a Dice coefficient of 0.830 on the LIDC dataset, substantially higher than the 0.663 achieved by conventional approaches. Through its encoder-decoder architecture and skip connections, U-Net effectively integrates multi-scale features to achieve precise segmentation of nodule boundaries, demonstrating consistent performance across solid nodules, part-solid nodules and ground-glass nodules. Although SegU-Net slightly underperformed U-Net in testing metrics, it offers advantages in computational efficiency and memory usage, making it more suitable for deployment in clinical settings [7]. Furthermore, AI has shown promising results in the automatic detection of coronary artery calcification (CAC), exhibiting high agreement with expert evaluations (ICC = 0.904) and significant predictive power for major adverse cardiac events (MACE) and lung cancer occurrence (AUCs above 0.8) [6]. This underscores the potential of AI in integrated diagnostic assessments, particularly in resource-limited regions.

3. Application of AI in Malignant Pulmonary Nodules and Differentiating Benign

The widespread adoption of LDCT (low-dose computed tomography screening) has yielded a sharply higher pulmonary nodule detection rate. Accurately distinguishing between malignant nodules and benign is crucial for ensuring that patients receive timely treatment while avoiding unnecessary surgeries [8]. In recent years, breakthroughs in artificial intelligence (AI) and deep learning have provided innovative solutions for efficient pulmonary nodule diagnosis through medical image analysis.

A key advantage of AI in classifying pulmonary nodules lies in its powerful ability to extract and quantitatively analyze imaging features. Traditional evaluation depends on visual assessment of characteristics such as nodule size and density by physicians, which can be subjective and inconsistent. In contrast, AI algorithms can automatically segment nodules and extract subtle, subvisual imaging features—known as radiomics features, including texture and wavelet characteristics—enabling the construction of more objective and accurate diagnostic models. Research has validated that deep learning algorithms applied to CT imaging excel in differentiating benign from malignant nodules, evidenced by AUC scores between 0.88 and 0.936, which denote a strong diagnostic ability [9, 10]. For instance, one study reported that an AI model achieved a sensitivity of 66.5%, specificity of 78.8%, and accuracy of 73.4% in diagnosing malignant nodules [11].

More importantly, multiple head-to-head studies have demonstrated that the diagnostic performance of AI can match or even surpass that of experienced medical teams. A study involving 506 CT images found that an AI model achieved a sensitivity of 0.80, specificity of 0.84, and accuracy of 0.83, outperforming seven different physician groups—including radiologists, oncologists, and multidisciplinary teams (MDTs) [9]. Beyond superior accuracy, AI enhances diagnostic consistency, reduces physician workload, and minimizes variability caused by factors such as fatigue.

Moving beyond binary classification, AI also shows promise in predicting specific pathological subtypes of lung nodules. According to the World Health Organization (WHO) classification, the progression of lung adenocarcinoma includes precursor glandular lesions (AAH/AIS), minimally invasive adenocarcinoma (MIA), and invasive adenocarcinoma (IAC), each requiring distinct treatment strategies and having different prognoses. Research indicates that AI systems outperform clinicians in predicting pathological subtypes such as PGL, MIA, and IAC, with higher average AUC, accuracy, recall, and F1 scores [8]. This suggests that AI could offer refined decision support prior to surgery and aid in developing individualized treatment plans.

To further improve diagnostic precision, current research focuses on multi-modal fusion models that integrate imaging features, clinical information, and biomarkers. Predictive models combining AI-analyzed CT features—such as lobulation, air bronchogram, and AI-predicted malignancy probability—with blood biomarkers like vascular endothelial growth factor (VEGF) and lung cancer autoantibodies are already being implemented. One such fusion model demonstrated significantly superior diagnostic performance (AUC = 0.946) compared to models based solely on CT features or biomarkers, with decision curve analysis (DCA) confirming its clinical utility [12]. Similarly, other studies have validated that combined imaging-clinical models outperform those using only imaging or clinical features in discriminating benign and malignant ground-glass nodules (GGNs) [13].

Despite its impressive performance, interpreting AI's decision-making process remains essential. Clinicians and researchers alike strive to demystify how AI arrives at specific diagnostic conclusions to build trust in its outputs. Feature importance analysis reveals that nodule size and morphological characteristics are the primary factors in AI judgments, while internal texture and background lung parenchyma also contribute meaningfully, though to a lesser extent [10]. This provides partial validation for the scientific basis of AI decisions, though the "black box" nature of deep learning models remains a challenge.

In summary, AI not only enhances the accuracy and efficiency of pulmonary nodule diagnosis as an auxiliary tool for physicians but also enables precision and personalized medicine by predicting pathological subtypes and integrating multi-modal data. As artificial intelligence (AI) technology continues to mature and global regulatory frameworks for medical AI steadily improve, AI-assisted diagnosis is expected to become an integral and indispensable component of the standard clinical management pathway for pulmonary nodules.

4. Conclusion

This study provides a systematic review of the merit of artificial intelligence in the detection of pulmonary nodules and the discrimination between malignant and benign cases. The results demonstrate that AI technology offers significant advantages in improving nodule detection rates, reducing missed diagnoses, and assisting in the differentiation of benign and malignant nodules. AI exhibits particularly strong performance in identifying small nodules

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and integrating multi-modal data, which can effectively alleviate the workload of physicians. The main contribution of this research lies in its comprehensive analysis of the latest advancements in AI for pulmonary nodule diagnosis, while also highlighting both the potential value and current limitations—such as insufficient model specificity and the "black box" nature of decision-making—in clinical practice. These findings offer important references for subsequent research, especially in areas such as multi-center validation and improving model interpretability. Future studies in lung cancer research should prioritize building larger, more demographically and clinically diverse datasets to enhance generalizability. They also need to develop more interpretable AI models for greater trust and develop strategies to promote deeper integration of AI into routine clinical workflows, ultimately advancing personalized and precise early lung cancer screening.

References

[1] Tang, X. The role of artificial intelligence in medical imaging research. BJR|Open, 2020, 2(1): 20190031.

[2] Xiao, Y. and Liu, S. Y. Current status and challenges of artificial intelligence industrialization in medical imaging. Oncoradiology, 2019, 28(3): 129-133.

[3] Xie, G., Yao, B. B. and Li, Y. The application value of artificial intelligence in improving the quality of CT image reconstruction of pulmonary ground-glass nodules. Hebei Medical Journal, 2025, 47(7): 1175-1178.

[4] Su, Y. C. and Zhang, X. Q. Application value of artificial intelligence-assisted diagnostic system in pulmonary nodule detection and benign-malignant judgment. CT Theory and Applications, 2024, 33(3): 325-331.

[5] Lancaster, H. L., Zheng, S., Aleshina, O. O., et al. Outstanding negative prediction performance of solid pulmonary nodule volume AI for ultra-LDCT baseline lung cancer screening risk stratification. Lung Cancer, 2022, 165: 133-140.

[6] Chamberlin, J., Kocher, M. R., Waltz, J., et al. Automated detection of lung nodules and coronary artery calcium using artificial intelligence on low-dose CT scans for lung cancer screening: accuracy and prognostic value. BMC Medicine, 2021, 19: 55.

[7] Rocha, J., Cunha, A. and Mendonça, A. M. Conventional Filtering Versus U-Net Based Models for Pulmonary Nodule Segmentation in CT Images. Journal of Medical Systems, 2020, 44: 81.

[8] Zhou, T., Zhu, P., Xia, K. and Zhao, B. A Predictive Model Integrating AI Recognition Technology and Biomarkers for Lung Nodule Assessment. The Thoracic and Cardiovascular Surgeon, 2025, 73(2): 174-181.

[9] Hu, W. G., Zhang, J., Zhou, D. Y., et al. A comparison study of artificial intelligence performance against physicians in benign-malignant classification of pulmonary nodules. Oncologie, 2024, 26(4): 581-586.

[10] Duan, X. X., Wang, M. K., Wang, L. J., et al. Diagnostic value of imaging features of pulmonary nodules and artificial intelligence in distinguishing benign and malignant pulmonary nodules. Journal of Clinical Pulmonary Medicine, 2025, 30(7): 1050-1054, 1063.

[11] Wang, X., Gao, M., Xie, J., et al. Development, Validation, and Comparison of Image-Based, Clinical Feature-Based and Fusion Artificial Intelligence Diagnostic Models in Differentiating Benign and Malignant Pulmonary Ground-Glass Nodules. Frontiers in Oncology, 2022, 12: 892890.

[12] Chetan, M. R., Dowson, N., Price, N. W., et al. Developing an understanding of artificial intelligence lung nodule risk prediction using insights from the Brock model. European Radiology, 2022, 32(8): 5330-5338.

[13] Yang, Z. W., Zheng, Z. Z., Li, B., et al. Clinical application of artificial intelligence system in predicting benign and malignant pulmonary nodules and pathological types. Chinese Journal of Clinical Thoracic and Cardiovascular Surgery, 2025, 32(8): 1086–1095.