

# Advances in the Application of Deep Learning in the Diagnosis of Respiratory System Diseases

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## Abstract

The incidence and mortality of respiratory diseases, including pneumonia, tuberculosis, lung cancer, etc., remain at high levels worldwide. Chest X-ray and computed tomography (CT) are the main screening and diagnostic tools for these diseases, but traditional imaging methods rely on the experience of doctors and have problems with subjectivity and consistency. In recent years, deep learning has shown great potential in the field of medical image analysis with its powerful automatic feature extraction and pattern recognition capabilities. Deep learning technology, especially convolutional neural networks (CNN), has developed from the early single disease classification to multi-task collaborative analysis, foci detection, risk assessment, etc. Especially in the imaging diagnosis of tuberculosis, pneumonia, and lung cancer, deep learning methods significantly improve the efficiency and accuracy of diagnosis. In addition, with the improvement of big data and computing power, the application of deep learning has been extended to foci detection, clinical auxiliary decision-making, and other fields. However, problems such as insufficient data standardisation, limited sample labelling, and model generalisation ability still restrict the clinical promotion of deep learning in the diagnosis of respiratory diseases. Future research should focus on multimodal image fusion, few-shot learning, and improved model interpretability, so as to promote the wide application of deep learning in respiratory diseases and improve the level of individualised diagnosis and treatment.

## Keywords

Deep Learning, Respiratory Diseases, Medical Imaging,  
Convolutional Neural Networks, Computer-Aided Diagnosis

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## 1. Introduction

Respiratory diseases are the most common and fatal diseases in the world. Pneumonia, tuberculosis, lung cancer, and interstitial lung diseases are all common respiratory diseases in clinical practice [1]. Chest X-ray and CT are the core imaging methods for screening, diagnosis, and follow-up, but traditional imaging diagnosis is highly dependent on the experience of doctors, with problems such as strong subjectivity, heavy reading burden, and insufficient consistency between doctors, which are more prominent in primary medical institutions and high-load screening scenarios. The application of high-resolution chest CT is becoming more and more extensive, but there are still limitations such as large differences between observers and poor evaluation repeatability [2]. With the development of artificial intelligence technology, deep learning has become a research hotspot for medical image analysis with its powerful automatic feature extraction and pattern recognition ability [3]. Unlike traditional machine learning that relies on artificial construction of features, deep learning can independently learn multi-level characteristics from the original image, effectively improving the efficiency and accuracy of tasks such as foci detection and disease classification. Its application has expanded from single disease identification to multi-task collaborative analysis, clinical assisted decision-making, and other directions. Therefore, systematically sorting out the application status, progress, problems, and trends of deep learning in the imaging diagnosis of respiratory diseases is of great significance to promote the clinical transformation of technology and improve the level of accurate diagnosis and treatment. This review focuses on the application of DL in the imaging diagnosis of tuberculosis, pneumonia, and lung cancer, as these conditions represent a significant global disease burden, feature prominently in medical imaging research, and showcase distinct stages of AI application maturity—from screening (tuberculosis) to differential diagnosis (pneumonia) and precision oncology (lung cancer).

## 2. Technical Foundations of Deep Learning in Medical Image Analysis

Artificial intelligence has broad application prospects in medical image analysis and other fields, which can effectively improve the efficiency of disease prevention and control as well as diagnosis and treatment. Deep learning, a pivotal branch of AI, achieves hierarchical feature extraction through multi-layered artificial neural networks, such as Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs), which can automatically extract feature representations from low to high-level [4], and plays an important role in image recognition and biomedical data analysis. As one of the core models of deep learning, the Convolutional Neural Network (CNN) reduces the number of training parameters through sensing field and weight sharing, and excels in large-scale image processing tasks. A typical CNN architecture comprises an input layer, convolutional layers, pooling layers, fully connected layers, and a Softmax layer. Through multi-layer non-

linear transformation, it realizes hierarchical abstraction of image features [5], which can identify image features that are easily ignored by doctors and improve the accuracy and objectivity of diagnosis. CNN has significant advantages in medical image analysis. It can automatically extract multi-level image features [6], realize end-to-end training, and improve diagnostic efficiency and objectivity.

With the rapid growth of medical image big data, massive and complex image data pose new challenges: on the one hand, the data dimension is higher, which requires the model to have stronger learning adaptability; on the other hand, the data is scattered and the structure is complex, and it is necessary to integrate information from different sources for analysis. Deep learning can extract implicit disease characteristics from large-scale medical image data by simulating the human brain for automatic feature learning, which has become the core technology and hot spot of current medical image analysis research.

### 3. Advances in the Application of Deep Learning for Pulmonary Tuberculosis Imaging Diagnosis

Tuberculosis remains a prominent global public health challenge, and the threat of multidrug-resistant tuberculosis continues to increase. Early detection and diagnosis are crucial to disease control and improved prognosis. The application of DL in TB imaging diagnosis is gaining considerable momentum. Computer-aided detection systems based on DL can automatically identify chest X-ray abnormalities and assess the risk of disease. It has been applied in many developing countries, effectively improving screening efficiency and alleviating the shortage of radiologists [7]. Its application has developed from the early classification of tuberculosis and non-tuberculosis [8], to the detection and localisation of lesions that are more suitable for clinical needs [9]. Compared with simple classification, foci detection can not only judge whether there is tuberculosis, but also mark the suspicious lesion area, which is more in line with actual clinical needs.

In terms of model construction, some studies have established a tuberculosis detection model based on target detection networks such as RetinaNet, which shows high detection efficiency [10]. At the same time, the application of migration learning technology has effectively alleviated the problem of insufficient image data. The TBNN model based on deep migration learning performs better than traditional machine learning, and its diagnostic ability is close to the level of radiologists [11].

In addition, some studies have compared three deep learning chest X-ray reading systems: CAD4TB, Lunit, and Qxr [12]. The results show that the screening effectiveness of the three is similar, and, in the context of these studies, was reported to be superior to that of experienced human readers. At the same time, these systems can also be used as triage tools to reduce the number of follow-up molecular tests while maintaining high sensitivity, thus improving screening efficiency. However, there are differences in the optimal thresholds across different regions and groups of people, and localisation verification and parameter adjust-

ment need to be carried out before the model is applied clinically. In the future, it is still necessary to further conduct large-scale, multi-centre, and real-world research to improve the stability and clinical promotion value of the model.

#### **4. Advances in the Application of Deep Learning for Pneumonia Imaging Diagnosis**

Pneumonia is a common highly hazardous infectious disease. The death rate among the elderly is on the rise. Its X-rays show lung inflammatory infiltration shadows. The early symptoms are not obvious, making it easy to miss a diagnosis or make a misdiagnosis. The research scope of deep learning in pneumonia imaging diagnosis has gradually expanded from the early two-classification tasks to multi-classification and multi-task scenarios to meet the clinical needs of different pneumonia subtype identification.

In response to the challenge of multi-classification diagnosis of pneumonia, some studies have proposed a CNN-enhanced cascading forest model based on semi-supervised learning [13], which extracts deep features through CNN, cascades forest mining image patterns, and uses unlabelled data in combination with pseudo-labelling strategies for multi-category classification of chest X-ray and CT images. The results show that a high accuracy rate has been achieved in the multi-category identification of bacterial and viral pneumonia, demonstrating good application prospects.

In addition, the intelligent diagnosis performance of pneumonia imaging has been continuously improved. In terms of model construction, there has been a study to combine DenseNet201 and CapsNet to build a hybrid network to classify the labelled chest film, with an accuracy rate of up to 99.01%, showing the efficient identification ability of deep learning in pneumonia multi-classification tasks [14]. At the same time, the application of multi-centre research and migration learning methods shows that deep learning models can achieve high-precision diagnosis with limited annotation data. For example, the COVNet model can accurately detect COVID-19 from chest CT scans, while distinguishing between community pneumonia and other non-pneumonia abnormalities. The sensitivity and specificity of COVID-19 in independent tests reach 90% and 96%, respectively, and the ROC-AUC is 0.96 [15].

In summary, the application of deep learning in pneumonia imaging diagnosis has gradually developed from early two-classification tasks to multi-classification, cross-modal, and clinical-assisted decision-making scenarios, showing high accuracy, good interpretability, and clinical usability, providing reliable technical support for improving diagnostic efficiency and quality and improving the prognosis of patients.

#### **5. Advances in the Application of Deep Learning for Pulmonary Nodule and Lung Cancer Imaging Diagnosis**

Lung cancer is currently one of the malignant tumours with the highest incidence

and mortality rates in the world. Low-dose CT screening has been proven to effectively reduce lung cancer mortality [16]. Against this background, deep learning has made remarkable progress in the imaging diagnosis of pulmonary nodules and lung cancer. Early studies utilized models such as CNNs, Deep Belief Networks (DBNs), and Stacked Denoising Autoencoders (SDAEs) to analyse lung cancer image data based on LIDC (Lung Image Database Consortium) to realise lung nodule benign and malignant discrimination accuracy rates that can reach 79% - 82% [17]. Subsequent research has developed network models such as 3D CNN, which are used for benign and malignant identification and malignant degree prediction of lung nodules in CT images [18], which can effectively assist imaging doctors to improve the efficiency of film reading and diagnostic accuracy. With the expansion of data scale and the improvement of computing power, the application scenarios of deep learning in lung cancer imaging diagnosis continue to expand. It has gradually extended from traditional lung nodule detection and benign and malignant classification to more complex clinical tasks such as histological subtype classification, TNM stage judgement, survival prediction, and recurrence risk assessment. Self-supervised learning models (such as UCLIF) based on large-scale three-dimensional chest CT data have performed excellently in the above tasks, achieving high AUC (for example, I-IV stage AUC can reach 0.91) [19], demonstrating the ability of such models to effectively mine latent image features and enhance multi-task predictive power.

In addition, the application of deep learning in the diagnosis of lung cancer has been extended to the molecular level. Related studies based on RNA sequencing data confirm that deep learning can effectively screen candidate markers with diagnostic value from high-dimensional gene expression spectra, and the prediction accuracy is as high as 98.44% [20], providing a new technical path for the early detection of lung cancer. In general, the artificial intelligence technology related to pulmonary nodules is gradually evolving from a single-task model to an integrated and highly reliable clinical auxiliary diagnosis system, which provides important technical support for the early accurate diagnosis, precise staging assessment, and individualized treatment of lung cancer.

## **6. Challenges in the Application of Deep Learning for Respiratory Disease Imaging Diagnosis**

Despite the great potential of deep learning, its clinical application still faces many difficulties. First of all, data standardisation is insufficient, and data collection, storage, and annotation in different institutions lack unified standards, resulting in large differences in image data formats and complex structures, increasing the difficulty of preprocessing, consuming computing resources, and affecting model performance.

Secondly, algorithm innovation and adaptability are still key. The non-linear and multivariate characteristics of respiratory disease diagnosis are obvious. Although deep learning can automatically extract complex features, it still faces sci-

entific problems such as model selection and parameter optimisation. The balance between model generalisation ability and accuracy still needs to be explored to ensure its stable operation in different scenarios. Bed.

Finally, the limited interpretability of many DL models (“black box” problem) undermines clinician trust and makes it difficult to identify failure modes. Along with the aforementioned issues of data standardization and model generalizability, these interconnected challenges must be addressed to facilitate safe and effective clinical translation.

## 7. Conclusion

The application of deep learning in imaging diagnosis of respiratory diseases has made remarkable progress, showing high accuracy and usability in early screening, foci detection, multi-classification tasks, and auxiliary clinical decision-making of common diseases such as tuberculosis, pneumonia, and lung cancer. However, problems such as insufficient data standardisation, limited labelled samples, limited interpretability, and generalisation ability of models still restrict their clinical promotion. Future research should focus on multimodal image fusion, small sample learning, and model interpretability to promote the extensive clinical application of deep learning in respiratory diseases.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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