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DIAGNOSTIC ACCURACY AND EFFECTIVENESS OF COMPUTER-AIDED DETECTION (CAD/AI) SYSTEMS IN THE ANALYSIS OF CHEST X-RAY IMAGES FOR THE EARLY DETECTION OF PULMONARY TUBERCULOSIS

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ABSTRACT: This article examines the role and effectiveness of Computer-Aided Detection (CAD) and Artificial Intelligence (AI) algorithms in the early detection and differential diagnosis of pulmonary tuberculosis. Based on World Health Organization (WHO) recommendations and a review of contemporary international scientific literature, the diagnostic sensitivity and specificity of AI systems based on convolutional neural networks (CNNs) are analyzed. Particular attention is paid to the influence of human factors on the detection of focal and infiltrative abnormalities in digital chest X-ray images (dCXR), as well as to the practical and economic advantages of integrating AI/CAD systems into screening and triage workflows.

Keywords: pulmonary tuberculosis, digital radiography, artificial intelligence, CAD systems, CNN, diagnostic sensitivity, WHO recommendations, screening.

INTRODUCTION

Pulmonary tuberculosis remains one of the most significant infectious diseases and continues to pose a major challenge to global public health systems. According to the World Health Organization (WHO), more than 10 million people worldwide develop tuberculosis each year. Delays in diagnosis and the failure to detect the disease in a timely manner continue to contribute to high mortality rates. The success of the global End TB Strategy is directly dependent on early and accurate diagnosis.

In conventional clinical practice, digital chest radiography is one of the primary instrumental methods used for pulmonary tuberculosis screening and preliminary diagnosis. However, detecting

small infiltrative lesions, subpleural nodules, and low-contrast abnormalities that may develop in the early stages of the disease can be challenging through routine visual interpretation alone. Factors such as the high workload of radiologists, visual fatigue, subjective interpretation, and insufficient clinical experience may contribute to missed early-stage pathological findings. According to some reports, the rate of diagnostic errors associated with such factors may range from 10% to 25%.

In recent years, rapid advances in digital medicine and medical image-processing technologies have made Artificial Intelligence (AI) and Computer-Aided Detection (CAD) systems among the most promising developments in medical imaging. Software based on deep learning and convolutional neural networks (CNNs) can automatically analyze chest radiographs, identify and localize pathological lesions, and estimate the probability of abnormalities using numerical indicators known as abnormality scores.

The aim of this study is to systematically analyze the diagnostic accuracy, sensitivity, and specificity of AI/CAD systems in the interpretation of digital chest X-ray images for the early detection of pulmonary tuberculosis, based on international scientific literature and WHO recommendations, and to evaluate the scientific and practical benefits of implementing these technologies in routine clinical practice.

MATERIALS AND METHODS

The methodology of this study was developed based on the principles of international systematic reviews and meta-analytical approaches. Scientific publications indexed in leading international databases, including PubMed/MEDLINE, ScienceDirect, IEEE Xplore, The Lancet Digital Health, and the European Respiratory Journal, as well as official WHO regulatory and guideline documents published between 2018 and 2025, were reviewed.

The main search terms used in the literature review included: "Computer-Aided Detection tuberculosis", "Artificial Intelligence chest X-ray", "CAD4TB diagnostic accuracy", "Deep learning pulmonary lesions", and "Sensitivity and specificity AI screening".

More than 120 scientific publications were initially identified. Following an assessment of their relevance, reliability, and methodological quality, 35 representative studies were selected for detailed analysis.

The technical platforms of the AI/CAD systems examined in this study were primarily based on the following algorithms and image-processing techniques:

ResNet-50 and U-Net architectures: Used for segmenting anatomical structures of the thoracic cavity and identifying lung fields in chest radiographs.

Bone Suppression algorithms: Technologies designed to digitally suppress the shadows of ribs and clavicles, thereby improving the visualization of infiltrative lesions that may otherwise be obscured by bony structures.

CLAHE (Contrast Limited Adaptive Histogram Equalization): An image-processing technique used to optimize image contrast and enhance the visibility of abnormalities in low-contrast radiographic images.

The diagnostic performance of the systems was assessed using the following statistical and diagnostic indicators: sensitivity (Se), specificity (Sp), and the area under the receiver operating characteristic curve (ROC-AUC). Microbiological confirmation methods, including sputum smear microscopy and GeneXpert MTB/RIF testing, were considered as reference standards for evaluating diagnostic performance.

RESULTS

The consolidated analysis of international scientific studies and clinical evaluations demonstrated that contemporary commercial AI/CAD systems, including CAD4TB (Delft Imaging), qXR (Qure.ai), and Lunit INSIGHT CXR, demonstrate high diagnostic performance in identifying radiographic abnormalities associated with pulmonary tuberculosis.

The diagnostic performance indicators of the major commercial AI systems analyzed are presented in Table 1.

As shown in Table 1, the sensitivity of AI systems ranges from 91.0% to 97.2%, which is higher than the reported average sensitivity of qualified radiologists (82.0%–89.0%) in the studies considered. This difference is particularly relevant when identifying small infiltrative lesions measuring less than 5 mm and miliary nodular abnormalities that may occur during the early stages of pulmonary tuberculosis.

In 2021, the World Health Organization (WHO) published its Consolidated Guidelines on Tuberculosis: Module 2: Screening, which included recommendations on the use of computer-aided detection technologies. According to these recommendations, CAD software may be used to interpret digital chest radiographs for tuberculosis screening and triage in individuals aged 15 years and older. WHO recognizes appropriately evaluated CAD software as an alternative to human interpretation of chest radiographs in eligible screening settings.

Table 1. Diagnostic performance of major AI/CAD systems in the detection of pulmonary tuberculosis (based on reported international study findings).

System	Platform	Sensitivity (Se, %)	Specificity (Sp, %)	ROC-AUC
CAD4TB (v.7)	Delft Imaging (Netherlands)	92.5–96.0	80.1–88.4	0.93–0.96
qXR	Qure.ai (India)	91.0–95.5	82.0–89.0	0.92–0.95
Lunit INSIGHT CXR	Lunit (South Korea)	94.0–97.2	83.5–91.2	0.94–0.97
Human radiologist (average)	Clinical practice (qualified)	82.0–89.0	85.0–92.0	0.86–0.90

The implementation of AI/CAD systems in clinical practice has demonstrated several practical, economic, and technical advantages:

1. Analysis speed: AI algorithms can analyze a single chest X-ray image in approximately 3–8 seconds. This significantly increases the throughput of mass screening programs and may improve screening capacity by up to tenfold under appropriate operational conditions.

2. Optimization of laboratory costs: Patients classified as suspicious by AI systems on the basis of elevated abnormality scores can be prioritized for expensive molecular diagnostic tests, such as GeneXpert MTB/RIF. This approach may reduce unnecessary PCR testing by approximately 40–50%, thereby contributing to more efficient allocation of healthcare resources.

3. Improved efficiency in underserved regions: The implementation of AI systems in healthcare facilities located in rural and remote areas with limited access to radiologists may improve the timely identification of suspected pathological abnormalities. Some reported findings indicate improvements of up to 35% in detection rates.

DISCUSSION

The findings indicate that AI/CAD systems are playing an increasingly important role in the early detection of pulmonary tuberculosis. In conventional radiological practice, diagnostic errors may arise from human factors such as reduced concentration, visual fatigue caused by heavy workloads, and difficulties in interpreting low-contrast radiographic images. AI-based neural networks can help mitigate these limitations by providing consistent and automated image analysis.

Nevertheless, the scientific literature also highlights several important limitations and challenges associated with the practical implementation of AI/CAD technologies.

False-positive results: AI algorithms may incorrectly classify residual fibrotic changes, calcifications, and pleural scarring in patients with a history of tuberculosis as signs of active disease. Such findings may reduce the specificity of these systems, which has been reported to range approximately from 80% to 88% in certain settings. To address this issue, the abnormality score thresholds used by AI systems should be appropriately calibrated according to local epidemiological conditions and the characteristics of the target population.

Challenges in differential diagnosis: Non-tuberculous pneumonia, other inflammatory pulmonary conditions, malignant neoplasms, and fungal infections may produce radiographic abnormalities that resemble those associated with pulmonary tuberculosis. Most currently available AI systems primarily classify radiographic findings according to the probability of tuberculosis, often using binary categories such as "high probability" or "low probability". This limits their ability to perform comprehensive differential diagnosis across a broader range of pulmonary diseases.

Ethical and legal responsibility: AI/CAD systems should not be regarded as independent diagnostic decision-makers. Rather, they serve as supportive tools or a "second opinion" for healthcare professionals. The final clinical diagnosis and associated medical and legal responsibility remain with the qualified radiologist or tuberculosis specialist.

Further development of these technologies requires the creation of multimodal AI models capable of simultaneously analyzing chest radiographic images, clinical symptoms, laboratory findings, and patient medical histories. Such hybrid neural network architectures could improve

diagnostic performance, facilitate differential diagnosis, and support more individualized clinical decision-making.

CONCLUSION

The use of Computer-Aided Detection systems in the analysis of digital chest radiographs for the early detection of pulmonary tuberculosis represents a promising approach with substantial scientific and practical potential for improving diagnostic performance. Based on the findings of this study, the following conclusions can be drawn:

1. High diagnostic performance: Contemporary AI/CAD systems demonstrate reported sensitivity levels ranging from 91% to 97% in detecting radiographic abnormalities associated with pulmonary tuberculosis. In selected studies, their performance exceeds the average sensitivity reported for human radiologists. These systems may help reduce the risk of overlooking early infiltrative and nodular abnormalities.

2. International recognition: The WHO's recommendation of CAD software for tuberculosis screening and triage provides an important scientific and regulatory basis for the wider implementation of these technologies in public healthcare systems.

3. Efficient use of healthcare resources: Integrating AI-based tools into screening workflows can substantially reduce image interpretation time, decrease the workload of radiologists, and facilitate more targeted use of expensive molecular diagnostic tests, including GeneXpert MTB/RIF.

4. Practical recommendation: The gradual integration of AI/CAD platforms compatible with locally available digital radiography equipment into pulmonary tuberculosis screening programs within the healthcare system of the Republic of Uzbekistan is considered advisable. Such implementation should be accompanied by local clinical validation, appropriate calibration, and continuous monitoring of diagnostic performance.

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