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**Original Research Article**

# Machine Learning Advancements in Tuberculosis Diagnosis: A Deep Dive into Medical Applications

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**Abstract**

Tuberculosis, or TB, is a respiratory illness that poses a significant threat to global human health, resulting in a substantial number of annual fatalities. Prompt evaluation and therapy are crucial factors in facilitating the full recuperation of the patient. Computer-aided diagnosis has emerged as a promising modality for the detection of TB. Numerous CAD methodologies employing machine learning techniques have been employed in the realm of TB diagnosis, particularly within the artificial intelligence or AI domain. This has consequently precipitated a notable resurgence of AI within the medical sphere. Deep learning, a prominent subdivision of AI, offers a substantial scope for the diagnosis of TB, a highly lethal disease. This review aims to elucidate the inherent constraints associated with conventional tuberculosis diagnostic methods, while providing a comprehensive overview of diverse machine learning algorithms and their pertinent implementations in the realm of TB diagnosis. Moreover, this study delves into the exploration of diverse deep-learning techniques that have been seamlessly integrated with other sophisticated systems, including genetic algorithm, artificial immune systems, and neuro-fuzzy logic. The current review provides an overview of several advanced diagnostic tools in the field of TB, including Lunit INSIGHT, CAD4TB, InferRead DR Chest, and qXR. These state-of-the-art tools have demonstrated promising capabilities in assisting with TB diagnosis through the application of AI. By summarizing the key features and functionalities of each tool, this review sheds light on the potential future prospects of AI-assisted TB diagnosis.

**Keywords:** TB diagnosis, Tuberculosis, Neural networks, Deep learning



## Introduction

Tuberculosis, a multifaceted and persistent ailment, arises from the ubiquitous presence of *Mycobacterium tuberculosis*, a microorganism. The microorganism in question exhibits a slow growth rate and possesses the ability to survive in both extracellular and intracellular environments. The pathogen may also enter a latency phase, during which it undergoes a period of dormancy. However, it can transition back to the exponential growth phase when the host's immune system becomes compromised [1]. In the year 2019, the esteemed World Health Organization (WHO) released a report indicating that approximately 10.0 million individuals were afflicted with TB, a highly contagious respiratory infection. Tragically, this infectious disease claimed the lives of 1.4 million individuals [2]. Moreover, TB stands as a prominent contributor to mortality on a global scale, giving rise to a pervasive health emergency that affects populations worldwide, with a particular emphasis on individuals afflicted with HIV infection and compromised immune systems. TB exhibits a disproportionate impact on developing nations, wherein a substantial burden of TB cases is observed. This burden is primarily attributed to the scarcity of proficient radiologists and adequate medical equipment within these regions.

Moreover, the rise of multi- and extensively drug-resistant strains of mycobacterium has posed significant challenges in the management and containment of tuberculosis. In numerous instances, there is a suspicion that the condition may deteriorate, progressing towards a state of complete drug resistance in TB, thereby exacerbating the difficulties encountered in its management. The identification of resistant strains of *M. tuberculosis* and the early detection of patients pose substantial challenges that will need to be addressed in the forthcoming decades. Artificial intelligence (AI) has emerged as a promising intervention in the battle against TB.

The utilization of computer-aided diagnostics (CAD) tools has proven to be highly advantageous in the interpretation of medical imaging, offering promising support to radiologists in the diagnosis of TB. Numerous contemporary studies have been undertaken to develop a diagnostic system characterized by superior performance. A CAD model was constructed for the purpose of diagnosing TB cavities. This model has the capability to detect and delineate regions of significance within the chest X-ray image. The present study addresses the limitations encountered in the current CAD systems, which have proven inadequate in accurately detecting TB cavities within the lung field due to the presence of overlapping anatomical structures. In a parallel manner, a CAD algorithm was devised with the capability to directly identify TB. The algorithm's characteristics enable the identification and extraction of rib images from the chest radiograph. This advancement facilitated the acquisition of a distinct visual representation of the pulmonary surface, thereby enabling the identification of lesions or opacities, consequently enhancing the precision of tuberculosis diagnosis [3]. Recent advancements in the field of AI programming have yielded significant progress in the development of algorithms capable of detecting a broader range of TB features. A TB detection channel was constructed utilizing a comparable framework that systematically integrated methodologies including masking, and chest radiograph examination, and texture assessment. The algorithm prioritized the identification and analysis of lesions and cavitary features, effectively encompassing the wide range of manifestations observed in TB.

A sophisticated CAD system was developed, incorporating image pre-processing techniques to optimize the quality of CXR images. This enhancement of image quality was achieved through the application of advanced algorithms within the model. The algorithm employed in this study initially performed lung field segmentation and subsequently extracted the pertinent features for analysis. These features were then subjected to classification techniques in order to make predictions regarding the existence of tuberculosis. The algorithm utilized the Shenzhen and Montgomery databases, both of which have been previously employed in multiple deep learning algorithms, resulting in a commendable accuracy rate of 95.6% [4]. The advancement of increasingly sophisticated algorithms, specifically deep learning models, has facilitated healthcare professionals in achieving enhanced precision in their clinical practice. The utilization of deep learning in conjunction with artificial immune system, genetic algorithms, and fuzzy logic has yielded a multitude of uncomplicated methodologies, thereby resulting in an augmented range of TB diagnostic specificity and efficiency. A novel mobile health technology has been devised utilizing deep learning techniques with the aim of enhancing TB detection in marginalized and developing areas. The objective of this study was to mitigate the delay in diagnosing the life-threatening disease by creating a technologically integrated social system capable of categorizing CXR images into various manifestations of tuberculosis [5]. In a similar vein, a pioneering approach for tuberculosis screening was developed utilizing deep learning techniques, incorporating a lesion-specific filtration system. In this study, the model extracted automated features based on the target variable using the available data.

The model underwent pre-training utilizing a transfer learning methodology, thereby effectively addressing the challenge of managing high-resolution X-ray images and training a multitude of parameters with a limited dataset. Consequently, the model exhibited exceptional performance. Moreover, the utilization of deep learning techniques has been employed in the development of cutting-edge tools such as Lunit INSIGHT, CAD4TB, qXR, among others, to facilitate the prompt and effective diagnosis of tuberculosis. This review primarily emphasizes the aspects that have previously exhibited their efficacy as a promising sub-field, and will consequently exhibit further refinement and potential for the upcoming phase of artificial intelligence in tuberculosis diagnosis.

**Tuberculosis: Understanding its Occurrence**

Tuberculosis is a respiratory tract infection caused by the airborne transmission of *Mycobacterium tuberculosis*, a bacterium that primarily targets the pulmonary system. However, the microorganism has the potential to disseminate to various anatomical regions, including the gastrointestinal tract, skeletal system, central nervous system, and endocrine glands, through diverse pathways originating from the pulmonary system. When an individual afflicted with TB experiences a paroxysm of sneezing, expectoration, or coughing, the mycobacterial pathogens are forcefully expelled from the respiratory system. In the event of inhalation by an individual in a state of optimal health, even in minute quantities, the aforementioned bacteria possess the capacity to induce tuberculosis. Individuals presenting with clinical manifestations are referred to as active tuberculosis (ATB) patients, while those with tuberculosis infection but lacking discernible symptoms are classified as latent tuberculosis (LTB) patients [6]. Patients with latent tuberculosis (LTB) infection do not possess the capability to transmit the disease to individuals in their vicinity. However, it is crucial to note that these patients are at a heightened susceptibility to progressing into active TB if they fail to uphold a lifestyle that promotes overall well-being. Furthermore, individuals exhibiting compromised immune systems as a result of infections such as HIV and diabetes, inadequate nourishment, or those predisposed to tobacco usage, are deemed to be at an elevated susceptibility for acquiring TB upon exposure to an individual infected with TB [7].

Extrapulmonary tuberculosis (EPT) refers to the bacterial invasion of various body organs, including but not limited to the bone, spine, and brain. Miliary tuberculosis, an infrequent manifestation of active TB, is characterized by the dissemination of mycobacterium throughout various systemic organs via hematogenous spread. Simultaneous infection of multiple organs, namely the lungs, spinal cord, and heart, characterizes the highly lethal nature of this particular form of TB disease. Active TB is additionally categorized into two distinct forms: extensively drug-resistant TB (XDR-TB) and multidrug-resistant TB (MDR-TB). MDR-TB is characterized by its persistence against first-line anti-tubercular medications, which can be attributed to the patient's inconsistent adherence to treatment or the provision of suboptimal and inadequate drug regimens. XDR-TB exhibits resistance to each of the first-line and second-line anti-tubercular medications, namely capreomycin, kanamycin, and amikacin [8].

**Traditional Methods to Diagnose Pulmonary Tuberculosis**

The timely identification of pulmonary tuberculosis is of utmost importance in order to optimize the management of the disease, thereby yielding favorable outcomes for both individual patients and the overall public health. This is achieved through the mitigation of community transmission, which is a significant benefit. The detection of TB is predicated upon a comprehensive evaluation of symptoms and a thorough examination of the patient's medical history. This is primarily due to the gradual manifestation of symptoms, which is attributed to the progressive proliferation of bacteria within the pulmonary system. A range of diagnostic tests are at one's disposal, encompassing chest radiography, microscopic examination, liquid culture with drug susceptibility testing (DST), LED fluorescence smear microscopy, LAM lateral flow assay, FL and SL line probe assays (LPA), Loopamp Mycobacterium tuberculosis complex assay, and Xpert MTB/RIF [9]. The evaluation of early pulmonary tuberculosis involves the utilization of sputum cultures, chest X-rays, and microscopic examination. On the other hand, the detection of drug-resistant strains is accomplished through DST.

Conventional diagnostic modalities are characterized by their protracted duration, which can inadvertently impede the timely identification of pathological conditions, thereby exacerbating patient distress and facilitating the continued spread of the ailment. Immunodiagnostic methodologies present expedited TB detection capabilities characterized by heightened sensitivity, albeit accompanied by considerable financial implications and a prerequisite for proficient personnel.

**Ai in Tuberculosis Diagnosis: An Overview**

The field of AI and machine learning (ML) encompasses a wide array of techniques utilized in the diagnosis of tuberculosis (TB). The aforementioned methods encompass semi-supervised, unsupervised, supervised, and transfer learning techniques. Supervised learning entails the process of training a model by utilizing input data (X) and its corresponding output data (Y) to discern discernible patterns. The utilization of an automated CAD system that integrates both deep learning and manually engineered features has been employed in the context of TB detection in chest X-ray images. This approach incorporates supervised learning techniques and pre-trained convolutional neural network (CNN) frameworks. The amalgamation of these methodologies facilitates the timely identification of TB through early screening.

Unsupervised learning is a computational approach that exclusively relies on input data (X) in the absence of output data, with the objective of clustering the data into distinct units through the extraction of salient features from the dataset. In the city of Bogota, Colombia, a study was directed to investigate the performance of supervised and unsupervised learning models in diagnosing TB and clustering patient data. The study reported a specificity of 71% and a sensitivity of 97% for TB diagnosis [10].

Semi-supervised learning is a computational approach that leverages a substantial dataset containing a limited number of labeled instances. This methodology holds significant relevance in addressing practical challenges by augmenting the precision of predictions through the utilization of unlabeled data. Active learning (AL), a specialized modality, involves soliciting user input to annotate untagged data, thereby enhancing accuracy. Transfer learning, a widely utilized technique in the field of medical imaging, involves the transfer of knowledge from pre-existing models to novel datasets. This approach has garnered significant attention due to its ability to achieve remarkable accuracy in the diagnosis of TB through the examination of chest X-ray images. The implementation of a hybrid methodology, which integrates a profound model alongside a classifier, has demonstrated enhanced performance outcomes. This approach has also exhibited the advantage of decreased training duration by means of refining pre-existing models [11].

**Enhancing TB Diagnosis with Deep Learning and Advanced Algorithms**

The potential of neural networks can be enhanced through the integration of complementary algorithms, including artificial immune systems, genetic algorithms, and fuzzy logic. The utilization of these integrated systems has been implemented for the purpose of TB diagnosis, demonstrating their efficacy and utility.

**Adaptive Neuro-Fuzzy Inference System**

Fuzzy logic (FL) is an approach that integrates numerical data with linguistic knowledge in order to facilitate rule-based mapping. The incorporation of reasoning by humans into knowledge-based systems is observed. Neural networks demonstrate exceptional proficiency in the realm of pattern recognition and classification, albeit they exhibit a dearth of explanatory capabilities. Conversely, fuzzy systems possess the capacity to elucidate decisions, yet they encounter difficulties when confronted with alterations in the environment [12].

The diagnostic procedure for TB involved the utilization of an adaptive neuro-fuzzy inference system (ANFIS), which incorporated various inputs such as sputum samples and chest X-ray images. The utilization of this approach is indicated in the context of rural regions characterized by constrained availability of medical practitioners. A comprehensive ANFIS model, consisting of a total of 159 rules, was developed and implemented in MATLAB. The model was further enhanced by incorporating a backpropagation algorithm to effectively minimize errors during the training process. A neuro-fuzzy approach was employed to analyze eleven symptoms associated with TB using MATLAB 7.0. The approach demonstrated effective learning and yielded favorable outcomes by utilizing Trapezoidal membership function and backpropagation [13].

**Genetic Algorithm with Deep Learning**

Genetic algorithms (GAs) play a crucial role in the domain of problem-solving, employing bio-inspired operators such as crossover, selection, and mutation. GAs are employed to model population dynamics through the generation of samples, their evaluation using fitness functions, and the iterative evolution of the most promising candidates across multiple generations. GAs were widely utilized in the field of AI prior to the emergence of neural networks (NNs). Unlike NNs, which heavily rely on large datasets, GAs possess inherent value in the exploration of potential solutions.

The genetic-neurological approach was employed for the diagnosis of TB. The model was trained using a backpropagation algorithm with Levenberg—Marquardt, while the selection of nine significant features was performed using a GA. The GA-NN model demonstrated a classification accuracy of 96.3%. In a similar vein, a hybrid algorithm was employed for the diagnosis of chest diseases, encompassing TB as well, through the utilization of an ANN implemented with the backpropagation technique. A comparative study was undertaken to validate the efficacy of the genetic-neuro method in the early diagnosis for tuberculosis [14].

**Genetic-Neuro-Fuzzy Inference System (GENFIS)**

The integration of a neural network, fuzzy logic, and genetic algorithm within an inference system facilitates the development of an adaptive model capable of engaging in self-training procedures for imprecise and uncertain data. The diagnostic approach employed in this study involved the utilization of a genetic-neuro-fuzzy inferential method for the identification of TB cases. The study was examined utilizing a case study involving a cohort of 10 patients, employing the MATLAB 7.9 software version. The model assessment was conducted utilizing the medical records of a cohort comprising 100 patients. The optimization of GNFIS was conducted utilizing a decision support engine, resulting in sensitivity and accuracy rates of 60% and 70%, respectively.

In a similar vein, the utilization of a GENFIS model was employed for the purpose of early detection and diagnosis of TB. Once more, a decision support system was employed to assess the medical records of 100 patients. In this study, a partitioning approach was employed to allocate the data into three distinct subsets. Specifically, 70% of the available data was designated as the training set, 15% was allocated for validation purposes, and the remaining portion was utilized for evaluating the performance of the model. The model under consideration exhibited a sensitivity of 72% and an accuracy of 82%, as reported in reference [15].

**Artificial Immune System (AIS) with Deep Learning**

Artificial Immune Systems (AIS) represent a burgeoning artificial intelligence methodology that draws inspiration from the intricate workings of the human immune system. The subject matter encompasses intricate issues such as classification, optimization, and pattern recognition, necessitating a significant computational capacity. Artificial immune systems (AIS) utilize principles derived from the biological immune system (BIS), renowned for its distributed database and de-centralized control mechanisms. This approach presents promising avenues for addressing diverse scientific and engineering challenges.

In the realm of medical science, AIS demonstrate considerable potential in the realm of diagnosing chest ailments, with a particular focus on tuberculosis. A study conducted in Turkey demonstrated a classification accuracy of 90% by employing AIS and Multilayer Neural Networks (MLNN) with the Levenberg-Marquardt (LM) algorithm [16]. An alternative methodology encompassed the utilization of an Artificial Immune Recognition System (AIRS) in conjunction with a fuzzy logic controller, thereby engendering a novel hybrid machine learning framework with the purpose of assisting medical practitioners in the process of diagnosis.

In order to optimize the diagnosis of TB, the SAIRS2 hybrid system was developed by integrating the Artificial Immune Recognition System (AIRS) with a Support Vector Machine (SVM) classifier. The primary objective of this integration was to mitigate the negative effects of diversity loss and selection pressure. The dataset was employed and subjected to analysis using the WEKA machine learning program. Moreover, the RAIRS2 hybrid system integrated the AIRS technique with real-world tournament selection (RWTS), a highly efficient mechanism commonly employed in genetic algorithms, to facilitate the diagnosis of TB. In this study, a novel approach utilizing agent-based modeling with AIS was employed to investigate the pathogenesis of TB and its intricate interplay with the immune system of the affected individual [17].

## Conclusion

Artificial intelligence has demonstrated promising capabilities in diverse diagnostic domains. Nevertheless, the utilization of AI in specific medical domains is currently in its nascent phase, thereby leading to a potential surge in research endeavors. AI has demonstrated its potential as a potent remedy for numerous life-threatening illnesses and the timely detection of such conditions. However, the adoption of novel technological advancements is characterized by a gradual pace, necessitating the replication of tasks and the surmounting of numerous obstacles inherent in the course of implementation. The implementation of AI is anticipated to yield notable modifications in the diagnosis of TB, consequently leading to significant advancements in the realm of research.

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