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# Effectiveness of bone suppression imaging in the diagnosis of tuberculosis from chest radiographs in Vietnam: An observer study

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ABSTRACT

*Objective:* To assess the effectiveness of bone suppression imaging (BSI) in the diagnosis of tuberculosis from chest radiographs (CXRs) in Vietnam.
*Materials and methods:* A total of 97 images (50 tuberculosis and 47 normal) comprised the dataset for this observer study with unanimous consensus of a panel of 3 expert radiologists. The participants were 9 Vietnamese radiologists (6 chest radiologists and 3 non-chest radiologists). Participants recorded their confidence levels regarding the presence of tuberculosis after reading a standard chest radiograph directly first and then after BSI processing. Receiver operating characteristic (ROC) analysis was used to evaluate participant performance. In addition, the change in participants' decision regarding the presence or absence of tuberculosis after BSI processing was recorded for each patient. Improvements in sensitivity and specificity were calculated.
*Results:* The average AUC for non-chest radiologists improved from 0.882 without BSI to 0.933 with BSI ($P = 0.048$). In addition, BSI improved sensitivity by 10.0% whereas specificity decreased by 2.8% among non-chest radiologists.
*Conclusion:* Using BSI improved the accuracy of tuberculosis diagnosis from CXRs, particularly by non-chest radiologists.

## 1. Introduction

According to the World Health Organization (WHO), an estimated 9.0 million cases (126 per 100,000 population) of tuberculosis (TB) were diagnosed globally in 2013, and 56% of these occurred in Asia [1]. Among Asian countries, the largest numbers of TB cases in 2013 were in Indonesia (460,000 cases; 183 per 100,000 population), the Philippines (290,000; 292 per 100,000 population), Myanmar (200,000; 373 per 100,000 population), and Vietnam (130,000; 144 per 100,000 population) [1]. Although these numbers have been decreasing since 1990, the incidence of TB remains unacceptably high, particularly in Asian countries.

Infectious diseases accounted for 25.3% of illnesses among Vietnamese in 2013, and TB ranked eighth among the top 10 infectious causes of death [2]. In 2013, the mortality rate from TB in Vietnam was 18 per 100,000 population; this was 90 and 11 times higher than in the United States and Japan respectively [1–4]. As a countermeasure, Vietnam now mandates employer-paid annual health checkups for employees; these checkups include physical examination, basic laboratory tests, abdominal ultrasound screening, and chest X-ray (CXR) evaluation. The growing prevalence of routine health examinations and availability of advanced imaging modalities will facilitate the early detection of diseases, including TB. Consequently, however, the number of images that chest radiologists must interpret will increase exponentially. In fact, radiologists not specially trained in chest imaging need to read CXR routinely out of necessity. In particular, given that CXR examination is a component of the mandated checkup, improving the interpretation accuracy of CXR and reducing the burden associated with reading these images are key goals.

Accurately interpreting the presence of early TB on CXR is especially challenging, because many anatomic structures, including bones, overlap the lung area. One recent tool used to facilitate disease

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diagnosis and thus decrease TB transmission is the computer-aided diagnosis (CAD) software for CXR, such as bone suppression imaging (BSI), which was developed by Konica Minolta in 2015 [5]. This algorithm uses computed radiography or digital radiography images as input and suppresses the signal from the ribs and clavicles to yield a soft-tissue–type image. However, the signal from fine structures such as disease lesions and blood vessels remains the same in a BSI-processed image as in the original CXR image, thus potentially improving interpretation accuracy and efficiency. In the current study, we evaluated the effectiveness of BSI for the diagnosis of TB by Vietnamese radiologists using CXR images obtained from Vietnamese subjects.

## 2. Materials and methods

### 2.1. Image collection and classification

CXRs were obtained at MEDIC Medical Centre (Ho Chi Minh City, Vietnam). Among 352 CXRs representing individual patients radiographed between September 2015 and June 2016, a diagnosis of TB was found in 262 and 90 were classified as normal by 2 chest radiologists who each had more than 20 years of experience. From the 262 TB images, we excluded 108 with TB lesions of 40 mm or larger, 8 with multiple abnormalities, and 30 with overt TB (determined as noticeable at a glance by 3 expert radiologists); the remaining 112 images were selected for this study. We then randomly selected 15 images each from the 112 TB and 90 normal images for use during a training session and 100 images (50 TB and 50 normal) for the observer study. A third chest radiologist with more than 20 years of experience reviewed the 100 images for the observer study to confirm their classification and excluded 3 of the 50 normal images because they contained potentially confusing abnormalities such as subtle infiltration shadow. Therefore, a total of 97 images (50 TB and 47 normal) comprised the dataset for this observer study with unanimous consensus of a panel of 3 expert radiologists (Fig. 1).

### 2.2. Study participants

Nine radiologists with an average of 16 years of experience participated in the study, namely 6 chest radiologists and 3 non-chest radiologists (i.e. Breast and pediatric radiologists) (Table 1). The three radiologists who reviewed the images for inclusion in the study were not included as participants. The purpose, experimental method, and expected results of the study were explained to the 9 radiologists, who agreed to participate. This research was approved by the institutional review board of MEDIC Medical Centre (SN/MDD28B16).

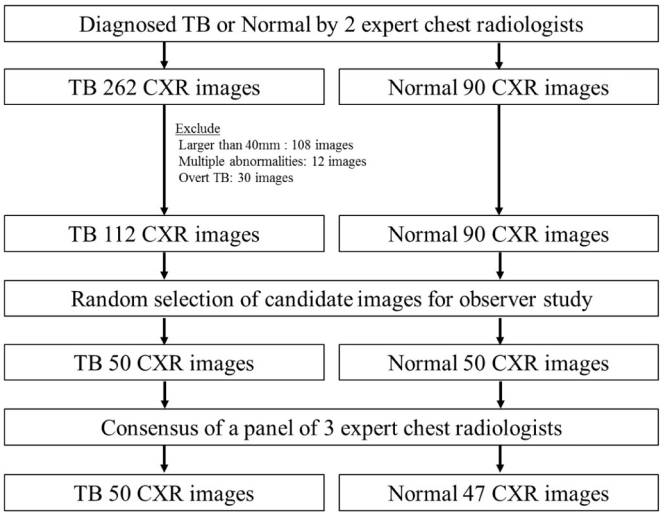


**Fig. 1.** Flowchart of image collection and classification for this observer study.

**Table 1**
Study participants.

| No. | Specialty | Radiological specialty experience (years) | Average no. of CXRs read daily |
|---|---|---|---|
| 1 | Chest | 26 | 200 |
| 2 | Breast | 2 | 10 |
| 3 | Chest | 27 | 30 |
| 4 | Pediatric | 19 | 250 |
| 5 | Chest | 13 | 400 |
| 6 | Chest | 14 | 180 |
| 7 | Pediatric | 21 | 100 |
| 8 | Chest | 17 | 100 |
| 9 | Chest | 7 | 150 |

### 2.3. BSI processing

BSI software was provided by Konica Minolta, Inc. (Hachioji, Tokyo, Japan). The BSI processing of CXR consists of 1) lung field segmentation and 2) bone recognition and bone signal suppression. During lung field segmentation, the signal from the lung field was extracted by identifying its characteristic boundaries: the lung apex, the outer rib cage, lung bottom (diaphragm region), and mediastinum. During bone recognition, the ribs and clavicles were extracted by using priori models (which were constructed by using large numbers of CXRs) and features from the target CXRs. In the bone signal suppression step, the bone signal of the extracted region was estimated and suppressed (Fig. 2). While the signal that originated in the bone was suppressed, the signal associated with fine structures such as blood vessels or abnormal shadows was unchanged from that in the original CXR. Consequently, the BSI processing improved the conspicuity of the lung field and any abnormal shadows that overlapped bones.

### 2.4. Study protocol and statistical analysis

An observer performance study of the 9 radiologists was conducted and the results were evaluated through receiver operating characteristic (ROC) analysis. The software program ROC Viewer (V11.4.0.7; Japanese Society of Radiological Technology, Japan) was used to display the original CXRs and BSI-processed images and to record observers' confidence levels by using continuous rating scales. The participants used a rating bar on the viewer to manually score their confidence regarding the presence of TB in the image. When a participant was absolutely positive that no TB was present, the confidence level was scored as 0 (non-existence of TB); when the participant was absolutely positive that TB was present, the confidence level was scored as 1 (existence of TB). The participants read the original CXR image first and determined the associated confidence level, after which they read the BSI-processed image and assigned a confidence score. To establish the criterion of the confidence level and understand the characteristics of BSI images, each radiologist participated in a training session using 30 images (15 TB and 15 normal images). In the observer study, the participants read 97 images (50 TB and 47 normal) both with and without BSI processing. The brightness of the monitors and the lighting in the reading room were kept constant among reviewers, and the participants set the viewing distance arbitrarily. For statistical analysis of confidence levels, ROCkit (V0.9.1; The University of Chicago, Chicago, Illinois) and the Dorfman–Berbaum–Metz multi-reader, multi-case technique (DBM-MRMC 2.2 software; University of Iowa, Iowa City, Iowa), were used. After the area under each ROC curve (AUC) was calculated, differences between the AUCs with and without BSI processing were evaluated. *P* values of 0.05 of less were considered to indicate statistically significant differences.