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Automatic detection of pleural effusion in chest radiographs☆

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ABSTRACT

Automated detection of Tuberculosis (TB) using chest radiographs (CXRs) is gaining popularity due to the lack of trained human readers in resource limited countries with a high TB burden. The majority of the computer-aided detection (CAD) systems for TB focus on detection of parenchymal abnormalities and ignore other important manifestations such as pleural effusion (PE). The costophrenic angle is a commonly used measure for detecting PE, but has limitations. In this work, an automatic method to detect PE in the left and right hemithoraces is proposed and evaluated on a database of 638 CXRs. We introduce a robust way to localize the costophrenic region using the chest wall contour as a landmark structure, in addition to the lung segmentation. Region descriptors are proposed based on intensity and morphology information in the region around the costophrenic recess. Random forest classifiers are trained to classify left and right hemithoraces. Performance of the PE detection system is evaluated in terms of recess localization accuracy and area under the receiver operating characteristic curve (AUC). The proposed method shows significant improvement in the AUC values as compared to systems which use lung segmentation and the costophrenic angle measurement alone.

1. Introduction

Although Tuberculosis (TB) incidence has declined by 1.5% per year over the last few years, the global disease burden remains high with 9 million TB cases and 1.5 million deaths in 2013 (World Health Organization (2014)). TB is a curable disease and the major challenge lies in early detection and notification. In high-burden low-resource countries, such as in sub-Saharan Africa, individuals reporting with TB symptoms at primary-care healthcare facilities are screened using chest radiography as the first examination due to its cost effectiveness and wide availability (Story et al. (2012); Theron et al. (2012); van't Hoog et al. (2013)). Subjects with positive findings on the chest radiograph (CXR) are usually referred to more time-consuming and expensive examinations such as sputum microscopy and molecular testing for confirmatory diagnosis.

Reading CXRs for signs of active TB requires well-trained personnel and this is a scarce resource in high TB burden countries. Moreover, humans reading large numbers of CXRs are prone to fatigue. Computer-aided detection (CAD) systems can address these issues by either assisting the readers with diagnosis (Giger et al. (2001)) or making a decision in absence of a reader (Muyoyeta et al. (2014, 2015); Jaeger et al. (2013b)). TB primarily affects the lung parenchyma and may cause diverse manifestations such as consolidations, infiltrates and cavitation (Roy and Ellis (2010)). Hence, most of the CAD systems analyze the lung fields for the presence of any parenchyma abnormalities (Hogeweg et al. (2010); Jaeger et al. (2013a)) with only some studies specifically focused on manifestations such as cavities (Shen et al. (2010); Xu et al. (2013)) or miliary TB (Koeslag and de Jager (2001)).

Extra-pulmonary TB affecting the hilum and pleura (pleural TB) is another common form of TB. Pleural TB accounted for 4% and >10% of all the TB cases in the United States (Baumann et al. (2007)) and Spain (Porcel (2009)), respectively. In this case, pleural effusion (PE) is often visible and TB is reported as one of the most common causes of PE (Porcel et al. (2014); Sutherland et al. (2012); Liam et al. (2000); Valdés et al. (1996)). The focus of our work is therefore the detection of pleural effusion (PE) in CXRs. PE is characterized by an abnormal amount of fluid accumulated in the pleural space, as shown in Fig. 1. Due to gravity, the fluid is located in the lower portions of the pleural cavity, defined as costophrenic (CP) recess. This is the region formed by the diaphragm and the chest wall and is the potential area to be analyzed for presence of PE.

As current CAD systems for TB detection are not specifically trained to analyze the CP recess, they may fail to detect TB if PE is the

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1361-8415/

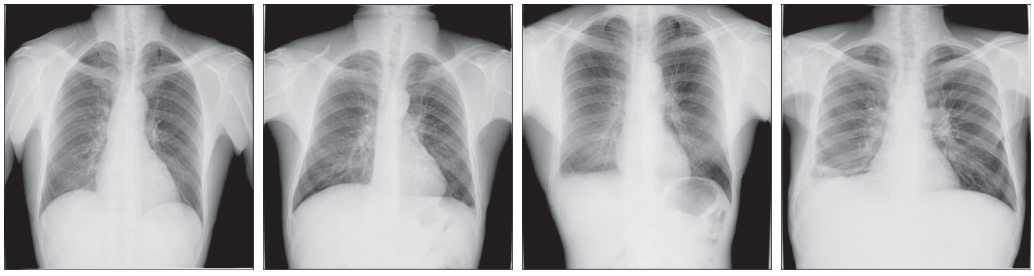

Fig. 1. Image categories as labeled by an experienced radiologist. (a) Completely normal image. (b) Left costophrenic recess with slight PE. (c) Right costophrenic recess with moderate PE. (d) Right costophrenic recess with severe PE.

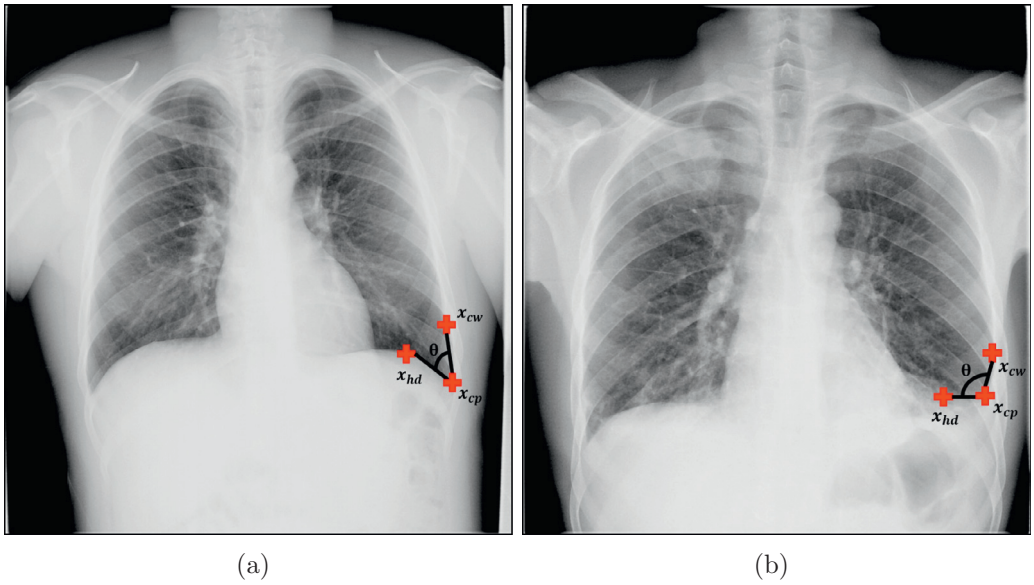

Fig. 2. Angle method proposed by Armato et al. (1998). (a) Normal CXR, (b) Abnormal CXR with a left blunt costophrenic angle. x_{cp}: costophrenic point, x_{hd}: hemi-diaphragm point, x_{cw}: chest wall point, θ is the measured CP angle.

only abnormality present in the CXR. Limited research has been done on automatic detection of PE. Avni et al. (2011) proposed a "bag of visual words" approach to differentiate between various pathologies in CXRs including a small PE dataset of 17 and 21 images with right and left PE, respectively. In a recent work by Bar et al. (2015), a deep convolutional neural network was used to differentiate between various pathologies on 433 chest radiographs including 44 CXRs with right plural effusion. Armato et al. (1998) developed a dedicated method which uses automatic lung segmentation to measure the angle between the hemidiaphragm and lateral chest wall, commonly known as the CP angle, to identify the amount of PE in each hemithorax. Fig. 2 illustrates the CP angle for a normal and an abnormal CXR with PE in the left hemithorax. The presence of fluid causes bluntness of the CP angle, leading to a larger angle measurement in contrast to an acute angle as it would be seen in a normal CXR. In our preliminary work on PE detection (Maduskar et al. (2013)), we calculated the difference in distribution of angle measurements between normal and abnormal hemithoraces with PE, and found considerable overlap between the two distributions. We therefore concluded that although angle measurement by itself is insufficient, it is an important feature and its accurate calculation is critical for PE detection.

In this work, we propose a CAD system for PE detection with two novel aspects: 1. Robust localization of the CP recess by means of combined anatomical landmark information and local refinement of the lung segmentation, and 2. PE detection using CP region and angle analysis. We define the CP point as the point of intersection of the lateral chest wall and the diaphragm as shown in Fig. 2. Accurate localization of the CP point is required for correct CP recess extraction and the angle measurement. In the previous approach by Armato et al. (1998), lung segmentation was used as the only structure for CP point extraction. In this work, in addition to the lung segmentation, the chest-wall is included as an additional structure for robust localization of the CP point. Further, the lung segmentation is refined in a local neighborhood around the detected CP point to obtain a more accurate angle measurement. In contrast to the previous work by Armato et al. (1998) where only the calculated angle was used to identify PE, our method also analyzes the region around the CP point. We introduce two region descriptors based on intensity and morphology information to improve PE identification. Results are reported on two separate systems trained to classify left and right hemithoraces, which is motivated by anatomical variation between left and right costophrenic recesses.

2. Data

The dataset used in this study was collected from two health centers in Lusaka, Zambia. The patients reporting to these clinics are TB suspects, i.e. they have clinical symptoms associated with TB. The CXRs were acquired using a digital Odelca-DR system with a slotscan detector (Delft Imaging Systems, The Netherlands) in the years 2009–2013 at a tube voltage ranging between 100–140 kVp adjusted per patient. The image resolution of the CXRs varied between 1560–2704 and 1520-2724 pixels in height and width, respectively, with a pixel spacing of 256x250 μm. A human reader (a trained medical student)