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Tanusree Chaudhuri*, Bo Gong, Sabine Krueger-Ziolek, Benjamin Schullcke and Knut Moeller

Automatic determination of lung features of CF patients in CT scans

Abstract: This paper describes a prototype of an automatic system for the detection and evaluation of Cystic fibrosis features (CF) in High resolution computed tomography (HRCT) Scans. The aim of this study lies in presenting this system as a decision support tool for radiologists in future. The CF features that have been detected and evaluated are Bronchiectasis and Mucus Plugging. This system recognizes Bronchiectasis as the presence of enlarged airways in pulmonary CF-CT slices whereas, Mucus Plugging has been recognized as clusters of high attenuation pixels. The dataset of this study consists of HRCT Scans of five CF patients of varying disease stages. Mean percentages of these CF features that were computed for each intercostal space, starting from the first to the fifth, fairly accurately match the different stages of the disease.

Keywords: 2d airway segmentation; computed tomography; cystic fibrosis; lung segmentation; mucus plugging.

1 Introduction

Computed tomography (CT) scans have been shown to be the most effective tool for assessing the progression of the Cystic fibrosis (CF) disease. On one hand the lung function tests provide functional information, and on the other hand CT Scans provide the related morphological information. Image analysis of CT Scans may improve the diagnosis of lung injury associated with CF [1]. The Brody Scoring system, used by experts to quantify CF features in CT scans, is time consuming and requires trained individuals for accurate results [1]. Also, one expert's interpretation may differ from another's. Additionally, a manual

system may not be as sensitive to the smallest possible abnormalities as an automated system would be. Hence, it is valuable to develop a standard automated system to obtain the Brody scores, which could serve as a decision support tool for doctors. In this study, an automatic system for detecting two CF features has been developed and evaluated.

2 Methods

The methods described in this section were applied on 2D images, that are axially reconstructed pulmonary HRCT (high resolution CT) data taken from the first to the fifth intercostal spaces of each patient. The proposed feature detection scheme comprises of several sequential steps: preprocessing and lung segmentation, followed by detection of the CF features. Airways of different sizes were detected for different CF stages using a combination of the grayscale reconstruction (GR) and intensity thresholding (IT) techniques. Moreover, regions of mucus plugging were detected by thresholding out low attenuation pixels from the lung fields that were segmented out from the original CT images. This feature detection scheme has been implemented on MATLAB R2015B.

2.1 Pre-processing and lung segmentation

This section commenced with low-pass filtering on the original CT slice to smooth the image. Following this, contrast enhancement was carried out on the smoothed image to create two different preprocessed images, pronounced on the intensity, for the airway detection techniques. This was done to reduce false detection by GR and for airway wall estimation, which is an important requirement for IT. These preprocessed images differed in terms of their display ranges: for GR the pre-processed image comprised of low intensities in the grayscale whereas, for IT the pre-processed image comprised of comparatively higher intensities.

*Corresponding author: Tanusree Chaudhuri, Institute of Technical Medicine, Furtwangen University, Villingen-Schwenningen, Germany, E-mail: tanusree.chaudhuri@hs-furtwangen.de
Bo Gong, Sabine Krueger-Ziolek, Benjamin Schullcke and Knut Moeller: Institute of Technical Medicine, Furtwangen University, Villingen-Schwenningen, Germany

After these preprocessing steps, lung segmentation commenced with creating a histogram of the CT numbers in the Hounsfield Scale (HU) of the original image. From this, the air threshold value (ATV) was computed as an average of the two largest peaks. Pixels below ATV were selected and subjected to basic morphological processing to produce the final lung mask. This binary mask was multiplied by the low intensity preprocessed image of GR to obtain the lung fields, that was provided as an input image for GR and mucus plugging detection.

2.2 Airways detection

In CT images of CF patients, enlargement of small or medium-sized airways, for depicting Bronchiectasis, has been regarded as an important feature of the Brody scoring system. Figure 1 shows the airways (marked in purple) that were detected by the automatic system. The grayscale reconstruction (GR) technique was used for detecting small airways and intensity thresholding (IT) was used for the larger ones.

2.2.1 Grayscale reconstruction

The grayscale reconstruction technique perceives the airways as the local minima of image intensities in 2D CT images and was therefore, applied to identify these regions of minimum intensities. This technique uses binary structuring elements (SE) of different sizes for detecting airways
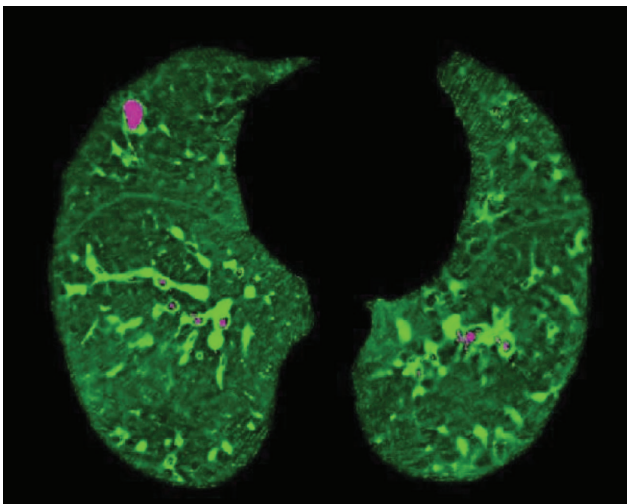

Figure 1: Detected airways in CF lungs. The detected airways are colored in purple. The airways with smaller sizes were identified by grayscale reconstruction, while the larger ones by intensity thresholding.

of different sizes. The steps of Grayscale Reconstruction technique [2] are listed as follows:

Step (i): $J = I \bullet B_0$

where denotes the morphological closing operation, I is the 2D image of the lung regions (section 2.1) and B_0 is a 4-connected binary SE for detecting the smallest airway. The marker image J identifies potential airways by increasing the gray-level values of their lumen.

Step (ii): $G = max\,(J \ominus B_0, I)$

where G is the grayscale reconstructed image and $\ominus$ denotes the morphological erosion operation. In the grayscale reconstructed image, the airways smaller than the SE get filled up with an intensity value which is proportional to the difference between the maximum and minimum pixel intensity values within the B-sized neighborhood of the airway lumen. The intermediate erosion step considerably eliminates other lung features with high gray-level values such as blood vessels.

Step (iii): $D = G - I$

where D is the difference image to identify the detected airways. The difference image displays the airways whose intensity values were altered in the steps above. Thresholding was applied on the difference image to retain only the detected airways. Steps (i) to (iii) are repeated with different sized SEs obtained by successive dilation of B_0.

The grayscale reconstruction technique was successful in detecting smaller airways within the size of SE used. However, its specificity to detect larger airways gets noticeably low as the size of the SE increases. This triggered restricting the maximum size of the SE to only four successive dilations of B_0. Such a limitation could have been eliminated in a 3D reconstruction of the complete airway tree after all 2D airway detections were made [2]. However, that lay outside the scope of this study, which led to the IT technique that was used to detect the larger airways.

2.2.2 Intensity thresholding

The pre-processed input image for this technique (Section 2.1) was subjected to thresholding to remove airway wall between the lung regions and the airway lumen, such that the airways appeared to occupy holes (consisting of background pixels) in the lung regions. Following this, basic morphological processing was done to retain airway lumen within a size range of [20, 260] pixels.

2.3 Mucus plugging detection

Regions of mucus plugging were recognized as clusters of local maxima of intensities in the segmented lung fields. Contrast enhancement was done on the segmented lungs in order to increase the intensities of these clusters to the highest value in the grayscale. After this, the enhanced image was subjected to thresholding to detect the potential mucus plugged areas. Additionally, area opening was done for removing small non-mucus plugged regions to get an image similar to the one shown in Figure 2.

A flowchart of the entire methods section has been summarized in Figure 3.
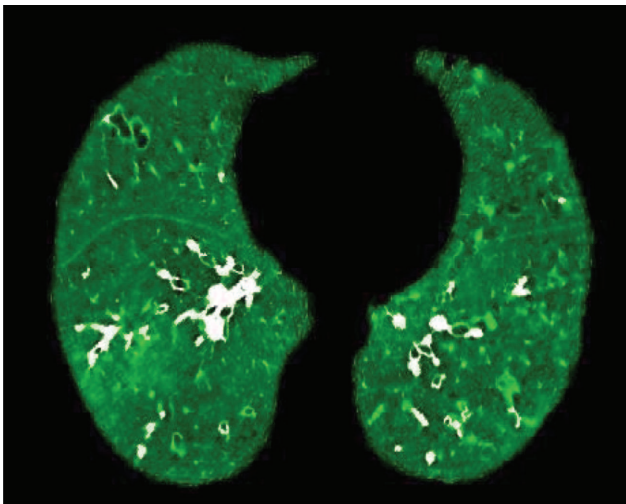
Figure 2: Mucus plugged regions in CF lungs. The detected potential mucus plugged regions have been marked in white.
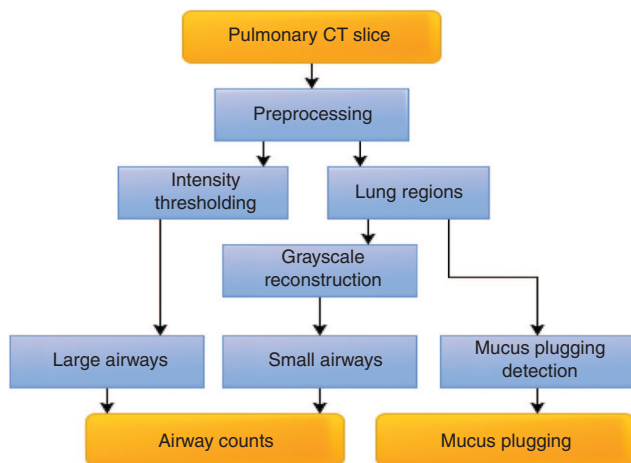

Figure 3: The flowchart of the proposed automatic system for Bronchiectasis and Mucus Plugging.

2.4 Patient specifications

The specifications of the five CF patients, whose HRCT scans were used for this study have been listed in Table 1.

3 Results

The following results were obtained on 3D CT scans of five CF patients of varying stages, that were determined by Spirometry tests. Feature detection was done on the 2D slices (from the first to the fifth intercostal spaces), axially reconstructed from the CT data. Algorithm parameters remained unaltered for all the CF patients, with a fully automatic generation of the ATV, used as the threshold value for lung segmentation. While creating the final lung mask, different parameter values of area opening and morphological processing were used for slices above and below the carina for each patient. Slices above the carina retained image objects consisting of more than 900 pixels whereas, slices below the carina retained image objects more than 600 pixels. Morphological closing used a flat disk-shaped structuring element (SE) having five neighbors for slices above the carina. Slices below the carina used the same SE, but with 25 neighbors for morphological closing. During CF feature detection all parameters were kept the same for slices above and below the carina. In grayscale morphological processing, the difference image was converted to a binary image (showing the detected airways) using two threshold values of 0.7 and 0.6 in the grayscale. The areas of detected airways and mucus plugged region were calculated and expressed as a percentage for each slice. Following this, the mean percentage of these areas were computed for each intercostal space to present the final plot.

4 Discussion

This paper describes the prototype of an automatic system which provides quantitative measurements of CF features in HRCT Scans.

Table 1: Patient specifications.

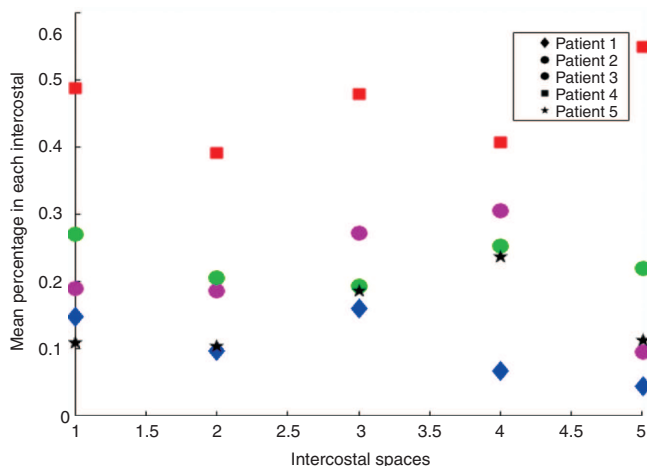| Patient	Age	Sex	BMI
Patient 1	34 years	Male	20.65 kg/m^2
Patient 2	31 years	Male	22.55 kg/m^2
Patient 3	36 years	Female	18.08 kg/m^2
Patient 4	53 years	Male	24.56 kg/m^2
Patient 5	50 years	Female	19.82 kg/m^2

Figure 4: Mean Percentage of airways in each intercostal. The areas of detected airways were expressed as a percentage in each CT slice.
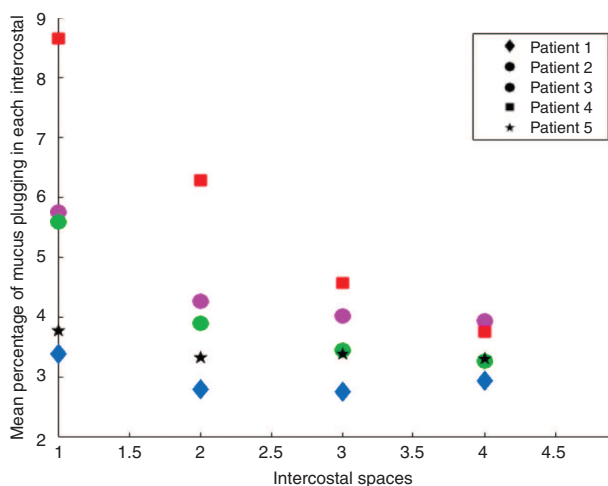

Figure 5: Mean percentage of mucus plugging in each intercostal.

The preliminary evaluation of the proposed automatic system fairly accurately depicts the severity of the disease stage in each patient. This can be observed for Bronchiectasis, represented by enlarged airways, in Figure 4. The accuracy in detecting mucus plugged regions poses a doubt, due to the high similarity in intensities between such regions and the blood vessels. However, this point could be refuted to a certain extent by noting the differences in Figure 5. A few false detections took place due to the closing operation performed in grayscale reconstruction. This challenge was encountered in the study conducted by Erkan et al. [3]. which expressed the difficulties posed by the surrounding lung tissues and vessel structures. In our study, this problem was dealt with by restricting the size of the SE to only two successive dilations of B_0 during erosion in GR. Additionally, it was challenging to choose the threshold values for airway detection. The airway wall thickness lies very close to the CT resolution limit [3], which made it difficult for intensity thresholding to estimate the airway wall boundaries for every slice.

5 Conclusion

This paper describes approaches for implementing a fully automatic system for quantifying and evaluating CF features in terms of simple criteria. The preliminary test results show that the evaluations by the automatic system display a considerable difference between the different disease stages.

Author's Statement

References

[1] DeBoer EM, Swiercz W, Heltshe SL, Anthony MM, Szefler P, Klein R, et al. Automated CT scan scores of bronchiectasis and air trapping in cystic fibrosis. Chest. 2014;145:593–603.

[2] Aykac D, Hoffman EA, McLennan G, Reinhardt JM. Segmentation and analysis of the human airway tree from three-dimensional X-ray CT images. IEEE Trans Med Imaging. 2003;22:940–50.

[3] Mumcuoglu EU, Prescott J, Baker BN, Clifford B, Long F, Castile R, et al. Image analysis for cystic fibrosis: automatic lung airway wall and vessel measurement on CT images. Conf Proc IEEE Eng Med Biol Soc. 2009;3545–8.