The Assessment of Chronic Obstructive Pulmonary Disease Progression by Computer Tomography Imaging Analysis

John Hebert da Silva Felix, Paulo César Cortez, Auzuir Ripardo de Alexandria

Departamento de Engenharia de Teleinformática (DETI/LESC)
Universidade Federal do Ceará (UFC)
Fortaleza, Brasil
{john, cortez}@lesc.ufc.br, auzuir@ifce.edu.br

Marcelo Alcantara Holanda

Departamento de Medicina Clinica
Hospital Universitário Walter Cantídio da Universidade Federal do Ceará (HUWC/ UFC)
Fortaleza, Brasil
marceloalcantara2@gmail.com

Abstract— Chronic Obstructive Pulmonary Disease (COPD) is a progressive lung disorder with increasing incidence with high morbidity and mortality worldwide. The objective of this study is to present the performance of this computational tool of our system in HRCT images of COPD patients submitted to different levels of continuous positive airway pressure (CPAP), a procedure that simulated the progression of the emphysema component of COPD. The system's measurements include: perimeter, area, mean lung densities, the 15th percentile point of lower density voxels and the histograms curves according to the radiological densities in Hounsfield units. A so called "follow up tool" of the system allows prompt comparison of all attributes among different CT slices. Therefore, 18 images of two patients with COPD in the supine position in 3 levels: in the apex, bases and hilum of the lungs submitted to the application of two pressure levels of CPAP applied non-invasively were analyzed. COPD progression as simulated by CPAP application can be characterized in details by HRCT quantitative imaging analysis.

Keywords-COPD;HRCT;images analysis.

I. INTRODUCTION

Chronic Obstructive Pulmonary Disease (COPD) is a progressive lung disorder with increasing incidence with high morbidity and mortality worldwide [1].

The early and accurate diagnosis of COPD is crucial in guiding therapeutic and preventive interventions such as smoking cessation. High-Resolution Computed Tomography (HRCT) is very accurate in diagnosing the emphysema component of COPD. However, HRCT imaging analysis by specialists are subjective and imprecise because the human vision limitation in distinguishing small gray scale variations, causing visual fatigue and errors [2]. On the other hand, recent advances in computer system analysis of CT images allow quantitative measurements of hyperaerated areas of the lungs and emphysema. [3], [4], [5], [6].

However, most computer programs specifically designed for this purpose do not have the ability to automatically compare sequential exams in follow up or longitudinal studies [7], [8].

We have developed a system that is able to compare multiple indices of hyperaeration or emphysema in sequential HRCT images, which is called "the follow up" tool.

The objective of this study is to present the performance of this computational tool of our system in HRCT images of COPD patients submitted to different levels of continuous positive airway pressure (CPAP), a procedure that simulated the progression of the emphysema component of COPD [9].

Materials and Methods

A. Study Subjects

Two individuals were tested. Both patients had the diagnosis of COPD according to the Global Initiative on Obstructive Lung Disease (GOLD) [10].

B. Acquisition of HRCT Images

HRCT images were acquired from a tomography equipment model Auklet (Toshiba TSX-003A, Tokyo, Japan) in the imaging service at the Hospital Universitário Walter Cantídio from Universidade Federal do Ceará.

For this purpose, according to HRCT protocol, images were obtained in the following conditions: collimation of 1.5mm, vision field of 312mm, tube voltage 120kV, tube electrical current 200mA, pulmonary window adjustment: center and width, respectively, - 600/1600 UH, reconstructed image size of 512×512 pixels. Tomographic slices were performed at supine position in 3 levels: apex (2 cm above the aortic arch), hilum (1 cm below the carina) and bases (2 cm above the diaphragm).

The simulation of Pulmonary Emphysema progression was done by application of two pressure levels of continuous positive airway pressure (CPAP), 10 and 15cmH$_2$O, by a nasal mask. This permits to increase pulmonary aeration and functional residual capacity and the emphysematous zones wherever they are inside the lung parenchyma. Patient information and data were maintained in secret in this work.

C.   Image Histogram

Histogram *h(nc)* of one image *g(x,y)* is the frequency's graphic of each image grayscale occurrences [11]. *(nc)* represents pixel grayscale level and *(no)* the number of pixel occurrences. In histograms, grayscale levels are presented in x-axis (for 8-bit images from 0 to 255) and the amount of pixels for each level in y-axis. Percentual from total pixels of the image can also be used [12].

It is possible to have a global description of grayscale levels of a image by its histogram. It's possible to have an unimodal form when there is only one object in the image. It can also be bimodal when the image is formed by two regions (object and background) and multimodal, when there are many objects in the image. It is presented a lung HRCT image in Fig. 1(a). Its respective histogram can be seen in Fig. 1(g).

D.   Feature extraction

Feature extraction is related to the performed measurements used to characterize objects and regions of interest in a given image. This is very important in Medicine, since these measurements permit detailed aided-diagnosis [13].

1)   Perimeter and area: Perimeter *(P)* of an object in an image is the pixels sum in the object edge, counted from an arbitrary pixel until achieve this pixel again. The area *(A)* of each object in an image is the pixels counting inside that objetct, limited by its border [14].

Before *P* and *A* calculation, the object contour is detected by the application of a mathematical morphology border extraction algorithm using one pixel size element structure which always permits a 4-connected border. This way, P and A are given by

$$P = \sum_{x=1}^{N} \sum_{y=1}^{M} b(x, y), \qquad (1)$$

$$A = \sum_{x=1}^{N} \sum_{y=1}^{M} r(x, y), \qquad (2)$$

where *N* and *M* are image dimensions, *b(x,y) = 1* is the object contour with 4-connected border, *r(x,y) = 1* corresponds to the object and *(x,y)* are the pixel coordinates in the image [14].

2)   Mean lung density and the 15th percentile point: Mean lung density (MLD) is the average of all pulmonay densities, measured in Hounsfield units (HU), calculated based in the histogram. Grayscale levels for a tomographic image are x-rays atenuation levels in HU. Then, MLD expression is given by

$$DPM = \frac{\sum_{d=i}^{N} d.h(d)}{\sum_{d=i}^{N} h(d)}, \qquad (3)$$

where N is the total number of grayscale levels in image (number of intensities in HU), *d* is the pixel intensity, *h(d)* is occurency frenquency of *d* intensity in HU and *i* is the initial intensity value in HU [8], [13].

A density value that is less dense than the 15th percentile point (PERC15) pixel is calculated based on the accumulated histogram of intensities in HU. PERC15 is defined as the threshold value where 15% of all pixels have lower density, i.e., values below -950 HU [8].

PERC15 is computed performing an accumulated histogram until the stopping point, which value is 15% [13]. An accumulated histogram that illustrates PERC15 selection is presented in Figs. 1 (j), 1 (k) e 1 (l).

E) The "follow up" tool

This computational tool automatically superposes the density histograms of two or more images for visual comparison (Fig 2). It also constructs a comparison table for two or more set of images.

II.   RESULTS AND DISCUSSIONS

A.   Results

The measurements extraction results are obtained after lung HRCT image segmentation through the proposed algorithm by Felix-Cortez-Holanda [9]. The purpose of this algorithm is to extract only lungs from the image, as shown in the second line from left to right in Fig. 1.
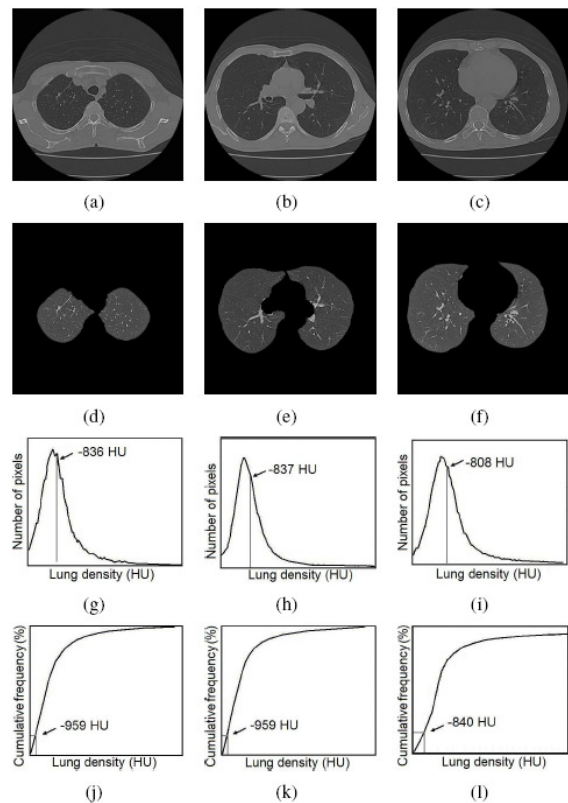

Figure 1.   HRCT images of a patient with COPD at (a) apex (b) hilum (c) base of the lungs; (d), (e) and (f) lungs' segmentation by

application of the Felix-Cortez-Holanda algorithm [14] and (g), (h), (i), (j), (k) and (l) their respective histograms and accumulated histograms.

Original lung HRCT images are seen at first line in Fig. 1. Histograms and accumulated histograms of the segmented images are shown in the last two lines in Fig. 1, respectively.

The calculated perimeter (*mm*), area (*mm^2*), MLD (*HU*) and PERC15 (*HU*) for 18 HRCT images of 2 patients with COPD using pressures of 0, 10 and 15 *cmH$_2$O* (first line), are shown in Table I.

TABLE I.　　RESULTS FOR 18 HRCT IMAGE MEASUREMENTS USING PRESSURES OF 0, 10, AND 15 CMH$_2$O

Images	Level of slice	Perimeter (mm)	Area (mm^2)	MLD (HU)	PERC15 (HU)
Patient 1	Apex0	824.84	18,523.60	-877	-986
	Apex10	832.77	18,992.50	-881	-986
	Apex15	849.99	18,937.10	-886	-987
	Hilum0	1,308.92	35,286.70	-883	-982
	Hilum10	1,319.33	36,571.80	-887	-983
	Hilum15	1,328.07	37,049.60	-899	-985
	Basis0	1,096.11	32,477.80	-851	-964
	Basis10	1,128.95	34,290.40	-852	-967
	Basis15	1,131.15	34,725.40	-855	-968
Patient 2	Apex0	588.86	11,036.20	-836	-959
	Apex10	587.35	11,143.30	-846	-964
	Apex15	605.18	11,929.80	-860	-969
	Hilum0	990.96	20,295.80	-837	-959
	Hilum10	1,006.68	21,912.60	-853	-965
	Hilum15	1,006.68	22,676.50	-871	-971
	Basis0	903.37	19,332.30	-808	-840
	Basis10	943.62	21,312.20	-829	-953
	Basis15	956.92	22,412.60	-853	-962

One example of superpose the density histograms of three images of Fig. 1 is shown in Fig. 2, for visual comparison.
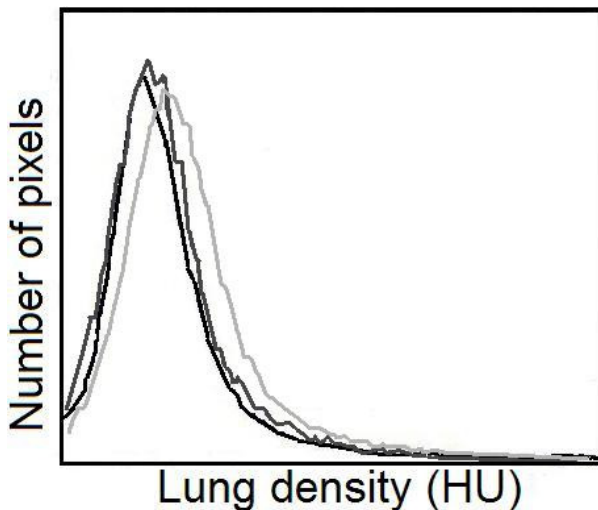

Figure 2.　Superpose the density histograms of three images of Fig. 1.

B.　Discussions

The results show that using the measurements presented in Table I, it is possible to perform a quantitative analysis in the HRCT images of patients with COPD. These results have a greater accuracy in COPD progress measurement which is generally performed by visual methods in films or computer screens.

The acquired images in different pressure levels applied to both patients with COPD show that the disease would be in progression, according to the values shown in Table I. Consequently, regarding to the results in this table, we can say that perimeter, area, MLD and PERC15 contain relevant information which can compound an appropriate COPD characterization and its progression.

The superposed histograms make possible MLD and Perc15 calculation, as well as the visual impression of COPD progression. This progression is characterized through histogram peak displacement. When this peak moves to left means that the disease evolution is occurring, i.e., it is becoming more severe.

The main limitation of this study was the small number of patients and images. Besides this, the obtained results show that the measurements used characterized properly the COPD progression, quantifying it with high precision. This computational analysis may aid in the diagnosis and in the follow up of patients with different degrees of emphysema.

III.　CONCLUSION AND FUTURE WORKS

A.　Conclusion

COPD progression can be characterized in details by quantitative HRCT imaging analysis.

The measurements used in this work make possible to monitor disease progression or its response to therapeutic interventions.

B.　Future Works

As future works, we indicate studies in a larger population sample, including new computational tools such as clustering analysis of hyperaerated areas and new measurements (such as airway wall dimensions), which will likely improve COPD assessment in CT images.

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