Multidetector computed tomography in emphysema: Quantitative assessment

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Pulmonary emphysema is characterized pathologically by an abnormal enlargement of air spaces distant to the terminal bronchioles, accompanied by destruction of the alveolar walls. Chest computed tomography (CT) and pulmonary function tests are usually used for the evaluation of emphysema. CT is widely used not only for an imaging of the radiological assessment of the thorax but also for the functional assessment including lung density and volume. Particularly, with the recent advances in MDCT technology, faster volumetric data can be acquired easily and used for evaluation of the volume [1].

Lung volumes are routinely assessed using pulmonary function tests. These tests allow global measurement of static inspiratory volumes (total lung capacity); static expiratory volumes (intrathoracic gas volume after normal expiration and the residual volume after maximum expiration); and dynamic volumes, like the absolute and relative forced expiratory volume in 1 sec (FEV1). However, measurement of unilateral or regional lung volumes is a major challenge in lung function testing [2]. Computed tomography (CT) yields densitometric measurements that are highly reproducible and that have been correlated with morphometric measurements of alveolar tissue [3-6]. New scanners require a breath hold of much shorter duration for imaging. In addition, reconstructions to 1.25 mm for calculation or interpretation can be made without exposing the patient to additional radiation [7]. State-of-the-art multi-detector CT imaging (MDCT) allows acquisition of the whole lung in thin sections of 1 mm. These high resolution 3D datasets (HR-MDCT) are mandatory to distinguish parenchymal alterations exhibited in emphysema and to assess regional variations [8]. Low attenuation areas on CT represent macroscopic and microscopic emphysematous changes of the lung [9]. Objective quantification of emphysema can be obtained by measuring the relative lung area occupied by pixels with attenuation coefficients below a predetermined threshold [10-12]. Quantitative evaluation of emphysema will be a key feature for serial follow-up examinations of patients with chronic obstructive pulmonary disease (COPD) [13,14].

The purpose of this study is to determine whether 3-dimensional CT densitometry reflects the severity of chronic obstructive pulmonary disease compared to the pulmonary function.
Methods and Materials

2.1. Patients population

A prospective study included 63 consecutive patients who were referred by chest physicians, between August 2011 and December 2012. All patients were suffering from chronic obstructive pulmonary disease.

The study was approved by the local ethics committee. All subjects were informed prior to the investigation.

2.3. Pulmonary functions tests (PFT)

Pulmonary function tests expressed as percentages of the predicted values based on age, sex, height and weight, were completed within 1 week before or after MDCT scanning. Spirometry was obtained in all subjects and included forced expiratory volume in 1 second (FEV1), forced vital capacity (FVC) and the ratio of forced expiratory volume in 1 second over forced vital capacity (FEV1/FVC). For descriptive purposes, COPD subjects were staged according to GOLD guidelines [15].

2.4- Computed tomography

2.4.1. MDCT Acquisition Parameters

Multidetector CT examinations were performed by using eight- multidetector row (Lightspeed-GE) in single breath-hold spiral technique without intravascular contrast material. Scans were obtained during full inspiration while the patient was in supine position, with the following parameters: 120 kVp, 250 mAs, 2.5mm collimation, 5-mm slice thickness, 1.25-mm reconstruction increment, and a pitch of 1 in chest reconstruction algorithm. Scan volumes were extended craniocaudally from the thoracic inlet to the costophrenic angles and were acquired in one breath-hold period. The average DLP was 440 (mGy-cm).

2.4.1. Quantitative MDCT Image Analysis

All raw data were transferred to Advantage workstation (AW) where Thoracic VCAR imaging software was used for CT estimation of emphysema. Lungs were segmented from the thoracic wall, the heart, and main pulmonary vessels, followed by segmentation of the individual lobes and the airways. The software provides automatic segmentation of the lungs and automatic segmentation and tracking of the airway tree. The software
provides quantification of Hounsfield Units and a color-coded display of the thresholds within a segmented region.

The extent of emphysema was quantified on each CT section using an automated "density mask" technique in which voxels with attenuation values below a specific threshold are highlighted. The cut-off level between normal lung density and abnormal low-attenuation lung was defined as -950 Hounsfield units (HU), because this value accurately predicts the macroscopic and microscopic extent of emphysema [16, 17]. The percentage of low-attenuation (%LA) emphysematous destruction was calculated for the whole lung.

2.5. Statistical analysis:

Statistical analysis was performed with SPSS software (SPSS version 16). The results expressed as mean ± SD for patient characteristics and CT extent of emphysema, and pulmonary function. Pearson's correlation was performed between pulmonary function data, and CT emphysema extent. A value of p < 0.05 was considered statistically significant.
Results

3.1. Demographic and clinical characteristics

26 females (41.3%) and 37 males (58.7%) with a mean age 53±8.9 years presented with chronic obstructive lung disease were included in the study. Their ages ranged from 35-66 years. The study included 35 patients had positive smoking history (see table 1).

3.2 Pulmonary function tests

Pulmonary function revealed 15 (23.8%) had mild restrictive defect, 9 (14.3%) had moderate obstructive defect and 39 (61.9%) had severe obstructive defect (see table 1).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>mean±SDs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td>63</td>
</tr>
<tr>
<td>Sex ratio (M/F)</td>
<td>37/26</td>
</tr>
<tr>
<td>Age (y)</td>
<td>53±8.9(35-66)</td>
</tr>
<tr>
<td>Smoking</td>
<td>35 patients (10-100 packs-years)</td>
</tr>
<tr>
<td>FEV1%</td>
<td>29.8±18.4(14-56)</td>
</tr>
<tr>
<td>FVC%</td>
<td>44.7±19.6(27-71)</td>
</tr>
<tr>
<td>FVC1/FVC%</td>
<td>52.4±16.4(35-72)</td>
</tr>
</tbody>
</table>

Table (1) patient characteristics and pulmonary function tests

3.3. Lung volume

The average lung volume was higher among patients with severe obstructive pulmonary function that was 3.23 L versus 3.04 L and 1.77 L for moderate obstructive and mild restrictive ones respectively.

Percentage of lung volume with attenuation values less than -950HU was 11.47% in patients with severe obstructive function, and it was 10.32% among patients with moderate obstructive function compared to 3.66% found among patients with restrictive function. A moderate significant relationship was found between lung volume less than -950HU and FVC, FEV1, and FEV1/FVC (P<0.05)(see Fig. 1 & Fig.2)
**Fig. 1:** 55-year old female patient had severe obstructive pulmonary function test. (a) Coronal reformat MDCT scan of the chest with densitometry overlay at a threshold of -950 Hounsfield Units and voxels with attenuation below the set threshold are colored blue. (b) Three-dimensional volume rendering image shows anatomic segmentation of lungs. (c) %LAA calculated by Thoracic imaging software provides the total low-attenuation volume. Total lung volume was 5.1366 L.

**References:** - Assiut/EG
Fig. 2: 60-year female had restrictive pulmonary function test. Coronal reformat shows Colour-coded overlay in blue of the emphysematous area with total lung volume 3.291 L.

References: - Assiut/EG

3.4. Extent of emphysema correlation with pulmonary function

Pearson’s correlation test showed good correlations between the quantitative assessments for the lower lung regions with -950 HU (%LA) and pulmonary function variables includes FVE1%, FVC% and FEV1/FVC%. It was negatively correlated between upper lobe and FEV1/FVC% (see Table 2) (see Fig.3)

<table>
<thead>
<tr>
<th>Extent of emphysema (-950 HU)</th>
<th>FVC%</th>
<th>FEV1%</th>
<th>FEV1/FVC%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>1.7512 L</td>
<td>0.5379 L</td>
<td>0.1808 L</td>
</tr>
<tr>
<td>Lobe</td>
<td>r value</td>
<td>p value</td>
<td>r value</td>
</tr>
<tr>
<td>-----------------------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>Right Upper lobe</td>
<td>-.252*</td>
<td>.046</td>
<td>-.205</td>
</tr>
<tr>
<td>Middle lung lobe</td>
<td>-.236</td>
<td>.062</td>
<td>-.199</td>
</tr>
<tr>
<td>Right Lower lung lobe</td>
<td>-.622**</td>
<td>.000</td>
<td>-.589**</td>
</tr>
<tr>
<td>Left upper lobe</td>
<td>.029</td>
<td>.821</td>
<td>-.007</td>
</tr>
<tr>
<td>Left lower lobe</td>
<td>.865**</td>
<td>.000</td>
<td>.867**</td>
</tr>
</tbody>
</table>

Table (2) correlation between the pulmonary function tests and extent of emphysema (%LA) below -950HU
Fig. 1: 55-year old female patient had severe obstructive pulmonary function test. (a) Coronal reformat MDCT scan of the chest with densitometry overlay at a threshold of -950 Hounsfield Units and voxels with attenuation below the set threshold are colored blue. (b) Three-dimensional volume rendering image shows anatomic segmentation of lungs. (c) %LAA calculated by Thoracic imaging software provides the total low-attenuation volume. Total lung volume was 5.1366 L.

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Fig. 2: 60-year female had restrictive pulmonary function test. Coronal reformat shows Colour-coded overlay in blue of the emphysematous area with total lung volume 3.291 L.

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Fig. 3: 40-year male patient had severe obstructive pulmonary function. Coronal reformat shows emphysematous areas coded by blue color in heterogeneous regional distribution with predilection to the right upper lung lobe (41%) and total lung volume was 4.5819 L.

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Conclusion

Watanuki et al [18] was the first done quantitative densitometry of the lung by measuring the mean value of pixel density in a region of interest drawn on each scan. Because normal lung at full inspiration has a mean density between -750 and -850 HU (on 10-mm slices) and emphysema has been defined to be more than 2 SD below the normal average density, this gave a value close to -900 HU as the threshold for calling an area emphysematous. According to work undertaken by Gevenois et al. [16, 17]and Madani et al [12] showed that the -950 HU voxel index is the cut-off value for emphysematous lung parenchyma on CT scans, which corresponds closely with macroscopic pathological examinations. Thus in this study, we used -950 as %LAA.

In this study, all examinations were performed in full inspiration. No CT examination were done with expiration. As some reports showed that inspiratory CT is equal to expiratory CT in the ability to quantify the pulmonary emphysemas [19, 20]. It is consistent with Gevenois et al. [17] who showed that expiratory quantitative CT is not as accurate as inspiratory CT to measure lung emphysema. However, the patients having difficulty in breathing can tolerate the inspiratory CT better than expiratory CT.

Published articles show significant correlation with pulmonary function tests, with coefficient correlation indexes as good as r = 0.82 [21], r = 0.66 [22], and r = 0.74 [23]. In the present study we found excellent relationship between the pulmonary function tests and quantitative assessments for the lower lung regions with -950 HU (%LA) that was in agreement with Gurney et al. who studied emphysema distribution and showed that predominantly lower lobe zones of emphysema are more likely to correlate with the results of pulmonary function tests than is the extent of emphysema in the upper lung zone, even if the upper lung is more severely affected [24].

In conclusion, multidetector computed tomography with automated 3- dimensional CT densitometry defining the severity of emphysema that's significantly related to the data of pulmonary function tests.
References


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