Quantification of Emphysema with Three-Dimensional (3D) Chest CT Scan: Correlation with Visual Emphysema Scoring on Chest CT, Pulmonary Function Tests and Dyspnea Severity

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Purpose

Chronic obstructive pulmonary disease (COPD) is characterized by progressive airflow limitation, which is not fully reversible and is associated with abnormal inflammatory response to noxious particles or gases. The morphologic phenotype of COPD include obstructive bronchiolitis and emphysema. Evaluation of emphysema in COPD is important and pulmonary function test (PFT) is standard for diagnosis and treatment of COPD. Also dyspnea is the most important clinical finding and is meaningful prognostic factor for patient's survival.

The purposes of this study include objective quantification of emphysema using 3-dimensional (3D) CT densitometry in patients with COPD. We also prospectively evaluated correlation between results from 3D CT densitometry with visual emphysema score, pulmonary function tests and dyspnea score.
Methods and Materials

Patients: Patients were prospectively enrolled in our study during the period of August to December, 2009, who were clinically diagnosed or suspected COPD. Our exclusion criteria include patients with other associated diffuse lung diseases, other lung diseases involving over one segment, bronchial asthma, severe cardiac or renal diseases, evidence of acute respiratory or systemic illness at presentation. Our patients consisted with total 28 patients (all men) with mean age of 72.4 yrs (age range: 54~88 years). 15 (53.6%) were smokers and 13 (46.4%) were ex-smokers.

CT techniques: CT scans were performed with Sensation 64 MDCT scanner (Siemens Medical System, Germany). CT scan was obtained with non-enhanced chest CT with full inspiration in supine position. CT scan was performed from thoracic inlet to lung base. CT scan parameters include 120 kVp, 250-280 mA, 1-mm table feed/rotation, 1-mm collimation, 0.7-mm interval, kernel B40f. Image reconstruction was done with thoracic algorithm (1-mm thickness).

CT Densitometry (Volumetric Assessment Technique): CT densitometry was done with lung parenchyma analysis software (Pulmo CT software, Siemens Medical Solutions, Germany) (Fig.1). Automatic recognition and segmentation of total lung parenchyma was made by differentiation of CT attenuation value. Threshold limits of lung parenchyma was -800 ~ -1000 HU. Airways, soft tissue surrounding lung, large vessels within the lung, and gastrointestinal structures were automatically excluded. Histogram display (Fig.2) automatically calculates lung volume occupied by pixels with a predetermined attenuation value, attenuation distribution and percentage, mean lung density and SD. Histogram also provides frequency distribution of voxels with specific attenuation value. Using histogram analysis, prediction of severity and distribution of emphysema can be done with measurement of mean lung density (MLD), lower attenuation volume at thresholds of each -950, -930, -900 HU, and percentile15% HU.

Visual Emphysema Score: CT images were reviewed by two radiologists (12 yrs of experience in chest imaging and senior resident) with consensus. CT scans were included from lung apex to base with 1mm thin-section axial image of MDCT. Four-point scale was used based on percentage of involving lung: 1 (up to 25%), 2 (25-50%), 3 (50-75%), 4 (75-100%). Grade for each axial image of each lung was added and divided by number of scans to yield emphysema score (range, 0~4).

Pulmonary Function Tests (PFT): According to 1994 American Thoracic Society standards, measurement of PFT consisted with Forced expiratory volume in one second (FEV1), forced expiratory volume in one second/forced vital capacity (FEV1/FVC), total
lung capacity (TLC), diffusion capacity for carbon monoxide (DLco). The value was expressed as percentage of predicted values. The time interval between PFT and MDCT was 46±12 days.

**Dyspnea Score:** The patient's subjective dyspnea score was clinically evaluated with modified Borg Scale Dyspnea Index (Grade 0~10).

**Statistical Analysis:** Using SPSS, Windows 15.0, Pearson correlation analysis was done for comparison of data from 3D CT densitometry with visual emphysema score, PFT and dyspnea score (P<0.01, 95% CI).
Fig. 0: Workstation images and table of data in a 68-year-old man with COPD. A. Axial image shows centriacinar emphysema seen as areas of hypoattenuation. B. 3D display of lungs reconstructed from MDCT data shows upper lobe predominance of emphysema, which is seen as less dense areas than middle to lower lung zones. C. Table obtained from the 3D CT data set shows total lung volumes, mean lung density and standard deviations.

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Fig. 0: Histogram and table of data from 3D CT data set in a 68-year-old man with emphysema. A. Absolute frequency histogram represents number of voxels of a specific density (eg. the absolute frequency of -900HU is 35,000). B. Cumulative frequency histogram represents a percentile of voxels below a specific density (eg. cumulated frequency of -950HU is 40% of total lung volume). C. Percentile(x)% is the highest density of the lowest densities in (x)% of total lung (eg. value of percentile15% in this patient is -993HU).

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Results

Mean time requirement for visual inspection of emphysema on all scans per each case was 15-20 minutes, while mean time requirement for 3D CT analysis and histogram display per each case was less than 5 minutes. Measurement of mean lung volume of lower attenuation at each threshold reveals 14.8±1.7%(-950HU), 23.1±1.9%(-930HU), 38.6±2.0%(-900HU). Mean visual emphysema score on CT was 1.7±0.18 and mean dyspnea score was 4.4±0.29.

Baseline patients’ characteristics, results of PFT, visual emphysema score, and dyspnea score are summarized on table (Fig.1). Correlation coefficients (r) between following parameters were obtained and summarized on tables: 1) 3D CT densitometry with results of PFT (Fig.2). 2) visual emphysema score with results of 3D CT densitometry and PFT (Fig.3), 3) dyspnea score with results of 3D CT densitometry and visual emphysema score (Fig.4).

Computed tomography (CT): On 1 mm thickness non-enhanced chest CT with lower attenuation area (LAA) at each threshold of -950HU, -930HU, -900HU, LAA was well correlated with clinical parameters at thresholds of -950HU and -930HU. Better correlation with PFTs was identified at threshold of -950HU.

Pulmonary Function Tests: LAAs below -930HU and -950HU were closely correlated with PFTs including FEV1/FVC and DLco, which is consistent result with previous studies.

Visual Emphysema Score: Correlation of visual emphysema score with DLco was noted, but no significant correlation of visual emphysema score with other PFT parameters was revealed in our study. Close correlation of visual emphysema score with lower attenuation volume (LAV) on CT densitometry (thresholds of -950HU and -930HU and percentile15%) was identified. Visual emphysema score was dependent on interobserver and intraobserver variability and technical factors including window setting.

Dyspnea Severity: LAV (below -950HU) on CT was well correlated with patient's dyspnea score. Further studies are needed including physiologic factors representing systemic status (body mass index, exercise capacity) and also evaluation of airway wall thickness.

Limitations: 1) Small number of patients limits generalization of our results, 2) Our study has no control group, 3) We did not evaluate morphologic and functional airway change, 4) Also we had difficulty in evaluation of small airways less than 2mm diameter, 5) There
is lack of study about effect of technical parameters of CT scanner including number of
detectors, section thickness, reconstruction algorithm, exposure condition, etc..
### Baseline patient characteristics and results of PFT, visual emphysema score, and dyspnea score

<table>
<thead>
<tr>
<th></th>
<th>Mean ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age, years</strong></td>
<td>72.4 ± 1.8</td>
<td>53-88</td>
</tr>
<tr>
<td><strong>Number of smokers</strong></td>
<td>15</td>
<td>NA</td>
</tr>
<tr>
<td><strong>3D CT measurements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean lung density, HU</td>
<td>868.1 ± 5.6</td>
<td>794-919</td>
</tr>
<tr>
<td>Lower attenuation volume, %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-950HU</td>
<td>14.8 ± 1.7</td>
<td>1.7-35.8</td>
</tr>
<tr>
<td>-930HU</td>
<td>23.1 ± 1.9</td>
<td>4.1-48.1</td>
</tr>
<tr>
<td>-900HU</td>
<td>38.6 ± 2.0</td>
<td>11.2-63.1</td>
</tr>
<tr>
<td>Percentile&lt;sub&gt;10&lt;/sub&gt;%, HU</td>
<td>969.5 ± 8.3</td>
<td>888-1024</td>
</tr>
<tr>
<td><strong>Visual emphysema score</strong></td>
<td>1.7 ± 0.2</td>
<td>0.777-4</td>
</tr>
<tr>
<td><strong>Pulmonary function tests</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEV&lt;sub&gt;1&lt;/sub&gt;, %predicted</td>
<td>59.6 ± 4.3&lt;sup&gt;*&lt;/sup&gt;</td>
<td>23-102</td>
</tr>
<tr>
<td>FEV&lt;sub&gt;1&lt;/sub&gt;/FVC, %</td>
<td>46 ± 2.5&lt;sup&gt;**&lt;/sup&gt;</td>
<td>26-71</td>
</tr>
<tr>
<td>DL&lt;sub&gt;CO&lt;/sub&gt;, %predicted</td>
<td>69.7 ± 3.8&lt;sup&gt;**&lt;/sup&gt;</td>
<td>44-107</td>
</tr>
<tr>
<td>TLC, %predicted</td>
<td>123.7 ± 4.5&lt;sup&gt;**&lt;/sup&gt;</td>
<td>81-182</td>
</tr>
<tr>
<td>Dyspnea score</td>
<td>4.4 ± 0.3</td>
<td>1.5-7</td>
</tr>
</tbody>
</table>

*NA not applicable. Percentile<sub>10</sub>: the highest density of the lowest lung densities in 15%*  
*FEV<sub>1</sub>: Forced expiratory volume in 1 second, FVC Forced expiratory vital capacity, DL<sub>CO</sub>: Diffusion capacity of lungs for carbon monoxide, TLC: Total lung capacity

**Fig. 0:** Baseline patient characteristics and results of PFT, visual emphysema score, and dyspnea score

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**Fig. 0:** Correlation coefficients of 3D CT densitometry with results of PFT.

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**Fig. 0:** Correlation coefficients ($r$) of visual emphysema score with results of 3D CT densitometry and PFT.

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**Fig. 0:** Correlation coefficients (r) of dyspnea score with results of 3D CT densitometry and visual emphysema score

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Conclusion

In patients with COPD and emphysema,

1) Objective quantification of emphysema using three-dimensional chest CT densitometry well correlates with DLco and FEV1/FVC.

2) Low attenuation lung volume below -950HU well correlates with DLco, FEV1/FVC and patient’s dyspnea severity.

3) Three-dimensional CT quantification of emphysema well correlates with visual emphysema score on two-dimensional chest CT scan.
References


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