Detection and quantification of the parenchymal abnormalities in emphysema using pulmo-CT

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Abstract

We aimed to determine the degree and extent of parenchymal abnormalities on pulmo-CT in patients with emphysema. The study group consisted of 29 patients (18 male, 11 female; mean age 57.9 ± 13). The diagnosis was based on clinical symptoms, pulmonary function tests (PFT) values, and chest CT findings. All of the patients CT scans were obtained during suspended deep inspiration from the apices to the costophrenic angles. The mean lung attenuation (MLD) and parenchymal abnormalities related to emphysema were quantitatively calculated with tables, histograms and graphics at the whole lung. The lung density measurements revealed a mean density of −898.48 ± 51.37 HU in patients with emphysema and −825.1 ± 25.5 HU in control group. In addition, mean percentage of subthreshold attenuation values was found as 12.03 ± 15.75 and 1.07 ± 0.83 in patients with emphysema and control group, respectively. Compared with control group, the patients with emphysema had a significantly lower inspiratory MLD (p < 0.05). Additionally, statistically significant correlations were seen between the MLD and percentage of subthreshold values (r = 0.44, p < 0.05). In contrast, there was poor correlation between PFT measurements and the subthreshold values.

In conclusion, pulmo-CT is a quick, simple method for quantitative confirmation of the presence of parenchymal abnormalities of lung as mosaic attenuation and should be used in combination with other radiological methods and PFT as it gives additional information to routine examinations in patients with emphysema.

Keywords: Emphysema; Parenchymal abnormalities; Mosaic attenuation; MDCT; Pulmo-CT; Quantification

1. Introduction

Pulmonary emphysema is defined as an abnormal enlargement of alveolar space distal to the terminal bronchioles, including alveolar wall disruption without obvious fibrosis. Clinico-functional and conventional radiological assessment of the chest are not highly accurate in detecting emphysema and in establishing the extent of the process of alveolar destruction. However, several computed tomography (CT) techniques are available for detection and quantitative assessment of emphysema in recent years. Many options have been proposed by different authors regarding CT technique [1–4]. These options provide quantitative evaluation of lung density and structure using sequential or spiral datasets with a visual scoring system and an automated quantitative evaluation by means of a “density mask” programs or percentiles [5].

In this study, we aimed to evaluate the parenchymal abnormalities such as mosaic attenuation, air-trapping, or cystic areas and the percentage of below threshold values in patients with emphysema using pulmo-CT software methods with inspiratory multidetector computed tomography scans (MDCT).

2. Materials and methods

2.1. Patient population

29 patients (18 male, 11 female; mean age 57.9 ± 13 [standard deviation]) with emphysema in stable clinical condition were included in the study from May 2003 to January 2005.
The diagnosis of emphysema was based on clinical symptoms, pulmonary function test (PFT) values, and chest CT findings. Patients were excluded if diffuse or focal parenchymal abnormalities affecting more than one pulmonary segment were identified. The patients who had bronchiectasis or pleural effusion, clinical history of bronchial asthma, severe cardiac or renal disease were also excluded. The pulmo-CT findings of the patients were reviewed in consensus. Ten individuals (6 male, 4 female; mean age 47.1 ± 12 [standard deviation]) who had normal chest CT findings and PFT results were selected as control group.

2.2. Pulmonary function test

The measures of PFTs included in the study were the forced expiratory volume in 1 s (FEV₁), forced vital capacity (FVC), total lung capacity (TLC), and FEV₁/FVC. The interval between PFT’s and CT examinations was less than 7 days for all patients (1–6 days).

2.3. CT examination and pulmo-CT study

CT examinations were performed by using a multidetector scanner (Siemens, Erlangen, Germany) in the helical mode without intravascular contrast material. Scans were obtained during full inspiration while the patient was in supine position, with the following parameters: 120 kVp, 150 mA, 2.5-mm collimation, 3-mm slice thickness, 10-mm reconstruction increment, and a pitch of 1.5. Inspiratory scans were selected because of reported greater accuracy in depicting anatomic detail. In addition, inspiratory scans were better tolerated than expiratory scans for the patients with emphysema. Scan volumes were extended from the thoracic inlet to the costophrenic angles and were acquired in one breath-hold period (8 s).

The pulmo-CT images were reconstructed with the pulmo-CT analysis package programme (Siemens Medical Systems) of the MDCT scanner. The trachea, main-stem bronchi, mediastinal structures, and soft tissues were selectively removed by pulmo-CT software. Furthermore, we manually removed the soft tissue structures, main bronchus, and vessels which could not be done automatically by pulmo-CT software. Lung density values were calculated according to the threshold values. Numeric analysis of lung attenuation were demonstrated in different forms including histograms, tables, and colored images (Fig. 1).

For visual analysis, all scans were reviewed to determine the presence of bronchiectasis, air trapping, mosaic attenuation, and other abnormalities. Air trapping was defined as the presence of areas of less than normal increases in parenchymal attenuation on CT scans. Mosaic attenuation was defined as the presence of parenchymal inhomogeneity on inspiratory scans. For visual evaluation, a window center of −600 HU and a window width of 1600 HU were selected in all instances.

2.4. Histogram

A histogram could show the volume, attenuation distribution, mean attenuation and standard deviation of attenuation of the whole lung. It provided a frequency distribution of voxels with specific attenuation numbers (in Hounsfield units) in the lung. The percentage of voxels with attenuation values below a specified level was defined as the lower attenuation volume at that threshold. Values for the lower attenuation volume at thresholds of >−769, −769/−864, −865/−894, −895/−915, and <−916 HU were measured by moving the boundary line on the histogram. A visual scoring system was performed using
Fig. 2. (a–c) The colors corresponding to HU values are displayed as a five-color scale (a). The different densities are marked with these colors (b). Color-coding of subthreshold areas can be displayed in red (c). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

The lung density measurements revealed a mean density (MLD) of $-898.48 \pm 51.37$ HU in the patient group and $-825.10 \pm 25.50$ HU in control group. Additionally, the overall relative area occupied by regions with subthreshold attenuation values was calculated and showed as histograms and colored images corresponded to the extent of parenchymal abnormalities (Figs. 3–5). Pulmo-CT and PFT results were summarized in Table 1. According to correlations, there were positive correlations between mean and subthreshold values ($p = 0.016$), and among pulmonary function tests (FEV$_1$, FVC and FVC, FEV$_1$/FVC) ($p < 0.0001$ and $p < 0.0001$).

The MLD showed significant correlations with TLC, ITGV, RV, and FEV$_1$/VC in both groups. MLD was found as $-825.10 \pm 25$ and $-898.48 \pm 51.37$ HU in control and patients group, respectively. Patients with emphysema had a significantly lower inspiratory MLD, when compared to the control group ($p < 0.05$). Additionally, statistically significant correlations were found between the MLD and percentage of subthreshold values ($r = 0.44$, $p < 0.05$) and correlations between PFT measurements and the subthreshold values were poor.

While one of the patients had increased MLD compared to the control group, the rest of the patients had decreased

<table>
<thead>
<tr>
<th>Group</th>
<th>Number</th>
<th>Mean</th>
<th>Std. deviation</th>
<th>Std. Error mean</th>
</tr>
</thead>
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<tr>
<td>Left</td>
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<td>901.5310</td>
<td>50.8692</td>
<td>9.4462</td>
</tr>
<tr>
<td></td>
<td>Control 10</td>
<td>821.4500</td>
<td>22.8781</td>
<td>7.2347</td>
</tr>
<tr>
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<td>Patient 29</td>
<td>893.3966</td>
<td>61.6512</td>
<td>11.4483</td>
</tr>
<tr>
<td></td>
<td>Control 10</td>
<td>828.2500</td>
<td>29.9339</td>
<td>9.4659</td>
</tr>
<tr>
<td>Mean</td>
<td>Patient 29</td>
<td>898.4310</td>
<td>51.3706</td>
<td>9.5393</td>
</tr>
<tr>
<td></td>
<td>Control 10</td>
<td>825.1700</td>
<td>25.5407</td>
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<tr>
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<td>49.8276</td>
<td>18.0140</td>
<td>3.3451</td>
</tr>
<tr>
<td></td>
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<td>101.2000</td>
<td>7.4207</td>
<td>2.3466</td>
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<tr>
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<td>42.2069</td>
<td>16.8234</td>
<td>3.1240</td>
</tr>
<tr>
<td></td>
<td>Control 10</td>
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<td>9.1894</td>
<td>2.9059</td>
</tr>
<tr>
<td>FEV$_1$/FVC</td>
<td>Patient 29</td>
<td>57.3103</td>
<td>15.1259</td>
<td>2.8088</td>
</tr>
<tr>
<td></td>
<td>Control 10</td>
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<td>6.3149</td>
<td>1.9969</td>
</tr>
<tr>
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<td>15.7176</td>
<td>2.9187</td>
</tr>
<tr>
<td></td>
<td>Control 10</td>
<td>1.0700</td>
<td>.3801</td>
<td>.2625</td>
</tr>
</tbody>
</table>

Note: FEV$_1$ = forced expiratory volume in 1 s, FVC = forced vital capacity. Std. = standard.
MLD which correlated with the clinical signs and PFT values. Air-trapping, mosaic attenuation or hypoattenuating areas suggesting emphysema were not detected in some patients having PFT compatible with emphysema. Emphysema diagnosis could be supported by pulmo-CT results. The percentage of subthreshold pixels \((-950/-1024)\) was 27.5% and MLD was \(-885.3\) HU in one patient (patient number 29) who had normal PFT values. Furthermore, the percentage of \(-949\) to \(-800\) HU pixels was found to be 54.2%. In this case, some additional information was acquired by using the frequency of pixels and distribution. In patient number 15, MLD was \(-963.1\) HU and FEV1/FVC was 46. For the same patient, the percentage of subthreshold pixels between \(-950\) and \(-1024\) HU was found as high as 77.7%. Interestingly, there were considerable findings on pulmo-CT while CT showed no radiological findings contributing to emphysema.

4. Discussion

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 CT and PFTs 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. There have been a number of reports on the usefulness of CT in assessing the pulmonary function including lung volume and density. As the range of CT values in the lung is strongly influenced by the content of air per voxel, quantitative and pathomorphological volumetric CT assessment of emphysema entities by an analysis of the range, frequency, and distribution of the CT values using MDCT at a certain threshold may reflect the accurate extent of the emphysema\[4,6-10\].

Advances in MDCT and workstation made it possible to obtain and analyze the 3D lung volume data in order to generate histograms of attenuation in HU for the lung\[9\]. Measurement of CT pixel attenuation values provides an objective method for quantitating emphysema. The low attenuation thresholds that have been used most widely to identify emphysema on conventional 10-mm-thick CT sections are \(-900\) or \(-910\) HU. Using thin-section CT scans at 1-mm collimation, Gevenois et al.\[10\] found that a lower attenuation threshold of \(-950\) HU correlated best with morphologic emphysema. In this study, pulmo-CT

\[
\begin{array}{cccc}
\text{Interval [HU]} & \text{Patient [%]} & \text{Reference [%]} & \text{Ratio [%]} \\
\hline
-1024.0 \text{ to } -950.0 & 0.9 & 1.6 & 0.6 \\
-949.0 \text{ to } -800.0 & 82.9 & 72.2 & 1.1 \\
-799.0 \text{ to } -600.0 & 12.3 & 20.7 & 0.6 \\
\hline
\end{array}
\]

Fig. 3. (a–d) CT and pulmo-CT findings of a healthy patient in control group. There is no abnormality on CT section (a) and pulmo-CT (b) results. The discrete red outlines on pulmo-CT image of lung density are in normal limits. The normal values are also demonstrated with table (c) and histogram (d). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)
results were compared with the healthy subjects and the gold standard of PFTs. They showed no correlation between the percentage of subthreshold areas and FEV1/FVC ratios. On the other hand, we observed significant correlation between percentage of subthreshold areas and MLD. It was experienced that, pulmo-CT was more valuable in detecting local air-trapping areas than evaluating total lung function. This result was parallel to expiratory CT studies that were carried out before with the same purpose. However, pulmo-CT is superior in showing local air-trapping areas, MLD and percentage of subthreshold pixels quantitatively.

Some reports showed that inspiratory CT is equal to expiratory CT in the ability to quantify the pulmonary emphysemas, whereas other reports focused on the use of expiratory examinations for quantitative assessment of emphysema [11–14]. However, the patients having difficulty in breathing can tolerate the inspiratory CT better than expiratory CT. For this reason, in this study inspiratory examinations were preferred and it was observed that all patients tolerated the CT examinations well. It was thought that, pulmo-CT performed on inspiratory CT is a valuable method as well as expiratory CT in the ability to quantify abnormally low attenuation areas of the lung.

The additional diagnostic information can be acquired with pulmo-CT especially in questionable circumstances. For example, CT findings of four patients diagnosed with the combination of clinical findings and PFT values were reported as normal in
Fig. 5. (a–d) Emphysema with PFT values of FVC:71, FEV1 43, FVC/FEV1:47. The areas of emphysema are well seen with color-coding pulmo-CT image (b) than CT image (a). The percentage of subthreshold areas is higher (34.5%) than normal. The obtained data are also shown on the table (c) and the graphic (d).

This study. But the patients had decreased MLD which is correlated with the clinical signs and PFT values and there were different colored areas corresponded to the parenchymal abnormalities of emphysema. Different percentages of air-trapping areas were reported in medical literature. Lucidarme et al. [8] and Hansell et al. [15] reported the percentage of air-trapping areas in emphysema patients as 35 and 34%, respectively. However, in this study, the percentage of air-trapping areas was found as 62.6%, which was more frequent than the other studies. It was thought that the difference between this study and the other studies results from the sensitivity of color encoding system used in this study. In contrast, the reported studies have used methods based only on visual evaluation. Furthermore, another finding that proves the reliability of this study was that the air-trapping and subthreshold values lower than $-950$ HU were not detected in control groups.

There are a number of studies that were carried out to detect air-trapping areas qualitatively. Among patients with bronchiectasis Hansell et al. [15] found a low degree of correlation between air-trapping score and FEV1, FEV1/FVC which is the global index of obstructive disease. There was no correlation with FVC. Lucidarme et al. [8] found poor correlation between visual score and FEV and the parameters mentioned above. In this study, a significant correlation was not found between FEV1, FEV1/FVC and pulmo-CT results.

Previous studies to date have used visual evaluation of thin-section high-resolution CT for the diagnosis of air trapping and emphysema [6–8]. For instance, Gevenois et al. [10] showed a correlation between abnormally low attenuation areas of the lung to diffusion capacity by means of high-resolution single-slice CT imaging. Volumetric scanning without the use of thin-section slices may potentially result in a misrepresentation of attenuation values resulting from volume averaging. In many studies, it has been stated that CT is a valuable method in demonstrating air-trapping and emphysematous areas. However, while in those studies lung densities were measured on a single slice or three sections slices and might result in misinterpretation [6–8,14–16]. In this study, MDCT allowed the researcher to make measurements on the whole lung. Making quantitative analyses on multiple slices allowed the researcher to derive more objective and correct results. In many patients with functional obstructive loss there was no air-trapping. This is because...
PFT reflects the whole lung function, not the localized lesions. Nevertheless air-trapping in end-expirium examination shows a localized pathology. The superiority of pulmo-CT is that unlike expiratory CT methods, it gives information about whole lung. Additionally, it seems that pulmo-CT will open new horizons in getting information about lung parenchyma, lung density and density distribution, and above all, the percentages of subthreshold-old values in patients with emphysema.

However, it should be kept in mind that pulmo-CT has some limitations. First of all, the efficiency of the pulmo-CT examination is based on patient cooperation. For example, insufficient inspiration causes a minimal decrease in lung density and result in misinterpretation. Although expiratory CT which is one of the methods used in radiological diagnosis of emphysema is as sensitive as PFT in detecting obstructive loss, this is not always the case.

As a conclusion, most important radiological findings related to emphysema are air-trapping and areas of decreased density. It is crucial to demonstrate these areas in making diagnosis. However, it is not always possible to show these areas with current techniques. A part of these areas can only be shown in expiratory examinations. Pulmo-CT is a quick, simple method for quantitative confirmation of the presence of air-trapping in and differentiation from compensatory hyperinflation. Pulmo-CT should be used in combination with other radiological methods and PFT, as it gives additional information for routine examinations in patients with respiration distress and the possibility of developing air-trapping.

References


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