Classification of Emphysema in Candidates for Lung Volume Reduction Surgery*

A New Objective and Surgically Oriented Model for Describing CT Severity and Heterogeneity

Kerstin Cederlund, MD, PhD; Ulf Tylén, MD, PhD; Lennart Jorfeldt, MD, PhD; and Peter Aspelin, MD, PhD

Objective: To elaborate a surgically oriented and objective model for classification of emphysema heterogeneity.

Patients and interventions: CT examinations of 66 candidates for lung volume reduction surgery.

Design: Emphysema severity was calculated by computer as the emphysema index (EI), a commonly used computer-based quantification that accurately assesses the extent of emphysema of a CT image. The distribution of the EI in different parts of each lung was illustrated in a diagram with the position in the lung (from cranial to caudal) on the x-axis and the EI on the y-axis. The slope of the fitted line was calculated. As a measure of the variation of the EI within each lung, the EI difference was calculated.

Results: A diagram was constructed with the absolute value of slope, k, on the x-axis and EI difference on the y-axis. This resulted in a diagram differentiating markedly heterogeneous, intermediately heterogeneous, and homogeneous emphysema. Nineteen patients fulfilled the criteria of bilateral markedly heterogeneous emphysema, 3 patients filled the criteria of bilateral intermediately heterogeneous emphysema, and 18 patients filled the criteria of bilateral homogeneous emphysema. Twenty-six patients had different types of emphysema in the right and left lung.

Conclusion: We present a method for classification of emphysema heterogeneity that is (1) objective, (2) surgically oriented, and (3) classifies both lungs separately.

(CHEST 2002; 122:590–596)

Key words: CT; emphysema; lung volume reduction surgery

Abbreviations: EI = emphysema index; HRCT = high-resolution CT; LVRS = lung volume reduction surgery

Lung volume reduction surgery (LVRS) for pulmonary emphysema, first described by Brantigan in 1957, was re-introduced by Cooper and coworkers in 1995. LVRS is used to increase the elastic recoil of the lung and improve diaphragmatic function by resecting parts of nonfunctioning emphysematous lung tissue while preserving those areas of the lung that are less severely diseased. Thus, from a surgical point of view, information on the extent and distribution of emphysema is mandatory. Also, the degree of emphysematous heterogeneity is a variable of interest, because it appears to affect the surgical outcome. Many different imaging techniques have been reported in the evaluation of LVRS patients, including various combinations of chest radiography, CT, scintigraphy, and MRI performed according to different protocols. CT is one that is well established and commonly used in selecting patients for LVRS. However, lacking “consensus on the best method for describing CT severity and heterogeneity,” the description of the findings has varied among investigators. This hampers comparisons between studies. Weder et al have presented a qualitative classification in which three types of surgically relevant morphologic types of emphysema distribution are considered.

*From the Department of Physiology and Thoracic Radiology (Drs. Cederlund and Jorfeldt), Karolinska Hospital, Stockholm; the Department of Radiology (Dr. Tylén), Göteborg University, Sahlgrenska University Hospital, Göteborg; and the Department of Radiology (Dr. Aspelin), Huddinge University Hospital, Huddinge, Sweden.

Manuscript received November 8, 2001; revision accepted March 19, 2002.

Correspondence to: Kerstin Cederlund, MD, PhD, Department of Physiology and Thoracic Radiology, Karolinska Hospital, SE 171 76 Stockholm, Sweden; e-mail: kerstin.cederlund@ks.SE

CHEST 2002; 122:590–596

Clinical Investigations
(Fig 1). For the purpose of quantitatively characterizing different types of emphysema, we chose the classification of Weder et al.⁹ as the basis for our work. The purpose of this study was to develop a model for classification of emphysema heterogeneity that is based on objective calculations, is applicable in a surgically oriented model, and offers a possibility to evaluate right and left lung separately; we also sought to test this model on a group of patients who were candidates for LVRS.

Of the 66 patients included in the study, 18 patients received LVRS. Because the purpose of the study was not to evaluate a correlation between emphysema morphology and surgical outcome, these patients were not further studied separately.

**Materials and Methods**

**Patients**

Between May 1995 and May 1997 (24 months), 66 patients underwent radiologic preoperative evaluation of emphysema at the Karolinska Hospital. The patients were referred to our hospital with a clinical suspicion of severe emphysema to determine whether they were suitable candidates for LVRS. The median age was 65 years (37 to 75 years), and there were 40 women and 26 men. The patients were classified into two groups consisting of 45 patients in the design group and 21 patients in the test group. The division of the investigated patients into two groups were made arbitrarily and without any bias. The local ethics committee approved the study.

**CT Technique**

All examinations were performed with a Siemens Somatom Plus scanner (Siemens, Erlangen, Germany) and included both spiral CT and high-resolution CT (HRCT). All examinations were performed in maximal inspiration and without IV contrast medium enhancement. The spiral CT was performed with 10-mm slice thickness and a pitch of 1.0 to 1.2 depending on the length of the lungs. The scanning direction was cranial to caudal. For spiral CT, the tube current was 210 mA, the exposure time (rotation time) was 1 s, and the voltage was 120 kilovolts. HRCT was performed with 2-mm slice thickness and 20-mm interspace covering the entire lung. For HRCT, the tube current was 275 mA, the exposure time was 1 s, and the voltage was 137 kilovolts. Both the 2-mm and 10-mm images were reconstructed with a high-spatial frequency algorithm (defined for the actual scanner as AB 7541). The number of images/slices included in the measurements for this study differed between patients from 9 to 13 images/slices. This number depended on the length of the lung and the area of the lung; the uppermost image was defined to be $> 67 \text{ cm}^2$ and the lowermost image was defined to be $> 100 \text{ cm}^2$ and without obvious partial volume effects of the diaphragm.

**Design of the Model**

To design a model for computer-based classification of emphysema heterogeneity corresponding to the three types of emphysema distribution depicted in Figure 1, we used data from 45 patients (the design group).

**Image Processing and Definition of the Emphysema Index:** The severity of emphysema was defined as an emphysema index (EI). This is an objective quantification, assessing the extent of emphysema in a CT image and eliminating the observer variability. These types of indexes have been validated by comparing quantitative CT data with histopathology specimens.²⁰–²³ The EI in this study was defined as the relative area of the lung tissue in each CT slice that was occupied by pixels between $950$ and $1,024$ Hounsfield units calculated on the 2-mm HRCT image. The images were analyzed using Siemens Pulmo CT software (Siemens). This software automatically recognizes the lungs, traces lung contours, presents histogram of attenuation values, and calculates the lung area occupied by pixels within a predetermined range of Hounsfield units.²⁴

**Diagram Illustrating EI for Each Lung:** The variation of EI between different parts of the lung was graphically illustrated in a diagram (Fig 2). The EIs for each lung were distributed along a straight line, which was determined by a least-square fit. The slope, $k$, of these lines, $y = kx + l$, was calculated. As a simple measure of the variation of EI within each lung, we calculated the EI difference as the highest EI minus the lowest EI for each lung.

To separate different types of emphysema we presumed that (1) a low value of EI difference represents homogeneous emphysema; (2) a high value of EI difference in combination with a low slope of the fitted line represents intermittently heterogeneous...
emphysema; and (3) a high value of EI difference with a steep slope of the fitted line represents markedly heterogeneous emphysema (either upper-lobe or lower-lobe dominance; Fig 2).

Testing the Model

To validate the model, calculations of k values and EI differences were also performed for 21 additional patients (test group).

Statistical Methods and Data Analysis

Regression analysis was used to evaluate the dependency between the distribution of EI in different parts of each lung and the position in the lung (from cranial to caudal). In addition to that, graphic methods were used to characterize the data. All analyses were carried out by the use of Microsoft Excel (version 2001; Microsoft; Redmond, WA), and a 5% level of significance was considered.

Results

Design of the Model

A diagram that included 90 lungs (45 patients) was constructed (Fig 3) with the absolute value of slope, k, on the x-axis and EI difference on the y-axis. Whether the slope was positive (lower-lobe emphysema) or negative (upper-lobe emphysema) was not considered.

According to our assumptions 1 to 3 (mentioned above), different types of emphysema are represented in a four-field manner in the diagram in Figure 3. Two discrimination lines can define these fields. The set of the discrimination level for k was determined by a statistical analysis showing that > 3, the k value of all the fitted lines were significantly different from zero. Thus, lungs with k > 3 were
defined as markedly heterogeneous emphysema. The EI differences for all lungs with $k > 3$ were $\geq 29$, and the value of 25 was chosen to discriminate between homogeneous and heterogeneous emphysema. These two discrimination lines are depicted in Figure 3. Therefore, for markedly heterogeneous emphysema, $k$ is $> 3$; for intermediately heterogeneous, $k$ is $< 3$ and EI difference is $> 25$; and for homogeneous emphysema, $k$ is $< 3$ and EI difference is $\leq 25$.

Testing the Model

To test the model an additional group of 21 patients (42 lungs) was also evaluated according to the model. Also in this test group, all $k$ values $> 3$ were significant and these lungs also had an EI difference $> 25$ (Fig 4).

Type of Emphysema in All 66 Patients

The total material consisted of 66 patients. All patients were classified according to the presented model. Nineteen patients fulfilled the criteria of bilateral markedly heterogeneous emphysema (12 patients with upper-lobe emphysema and 7 patients with lower-lobe emphysema), 3 patients fulfilled the criteria of bilateral intermediately heterogeneous emphysema, and 18 patients fulfilled the criteria of bilateral homogeneous emphysema. Twenty-six patients had different types of emphysema in the right and left lungs (Table 1).

Discussion

In this study a new method is proposed, based on objective measurements, for describing emphysema by CT in patients who are candidates for LVRS. The method allows for a surgically oriented classification into the categories that are markedly heterogeneous emphysema, intermediately heterogeneous emphysema, and homogeneous emphysema as adopted from Weder et al., establishing upper- or lower-lobe predominance and comparisons between the left and right lung.

During the last few years, LVRS has received much interest as a palliative treatment in selected patients with severe pulmonary emphysema. The results of many studies have shown symptomatic and functional improvement after this procedure. Despite documented improvements in mean physiologic values after the procedure, it remains unclear why some patients have a significant improvement in...
their major clinical symptoms as a result of LVRS and others do not. This may be a reflection of heterogeneous patient population, differences in selection criteria, different surgical technique, or the variation in describing emphysema may be a contributing factor.

There is no consensus with respect to radiologic classification of emphysema morphology. Systemic overestimation and moderate interobserver agreement may compromise subjective visual grading of emphysema. Therefore, objective methods must be preferred to achieve precise, reader-independent quantification of emphysema.

Many authors declare that heterogeneity is among the best predictors of improvement. This might be correct. However, some surgeons operate on patients with homogeneous emphysema and also report postoperative improvement in this group of patients. The question “What is heterogeneous distribution of pulmonary emphysema?” was pointed out in an editorial by Austin. Salzman also stressed the problem in a more recent editorial.

Because of the lack of conformity in methodology for assessing heterogeneity of emphysema, the description of the findings varies. For example, Wisser et al used the term homogeneous emphysema in contrast to the term bullous emphysema, whereas others use it for emphysema without any heterogeneity. Maki et al compared scores of heterogeneity from 0 to 4 in one zone with those in another, whereas others have compared differences within zones, eg, severely destroyed areas in regions of mild emphysema. Also, the comparison of differences in the extent of emphysema among adjacent segments has been used. Different quantitative CT measurements have also been used, ranging from calculation of the SD of mean lung attenuation to more sophisticated mathematical models.

In the present study, an objective model for classification of emphysema heterogeneity is proposed. Our model is not only objectively calculated, but also correlated to surgically relevant morphologic types of emphysema and enables separating the right and left lungs as well as the upper and lower lobes with predominant emphysema. Although the finding of different types of emphysema morphology in the right and left lungs is common (Fig 5), this patient

<table>
<thead>
<tr>
<th>Left Lung</th>
<th>Marked heterogeneous</th>
<th>Intermediate heterogeneous</th>
<th>Homogeneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marked heterogeneous</td>
<td>19*</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Intermediate heterogeneous</td>
<td>3</td>
<td>3*</td>
<td>3</td>
</tr>
<tr>
<td>Homogeneous</td>
<td>7</td>
<td>7</td>
<td>18*</td>
</tr>
</tbody>
</table>

*Patients with equilateral findings.
group is, to our knowledge, not reported in studies of postoperative outcome. We do not know whether they are only accepted for unilateral LVRS or whether they are rejected.

One problem in this study was the lack of a “gold standard” regarding emphysema heterogeneity. We chose to elaborate our classification model in two steps: first to establish the model based on 45 patients, and then to evaluate the classification on an additional 21 patients. The intention with our method was to create a model applicable in clinical practice. The only equipment necessary is computer software for quantitative CT measurements and linear regression analysis.

The type of CT unit, algorithm, slice thickness, software for EI measurements, and threshold value for EI that are used, however, are important factors that influence both the slope, k, and EI, and thereby the classification. Each investigator has to establish, according to their conditions, their own level for k and EI difference. The definition of k and EI difference for the three types of emphysema heterogeneity in this study is, possibly, valid only for the combination of these factors in our study. Therefore, the model should be regarded as a method of principle.

The objective classification of emphysema distribution presented here may both facilitate the selection of patients for LVRS, as well as comparison between different studies. The final value of our model in selection of patients and correlation with postoperative outcome has yet to be proved.

REFERENCES


---

**Figure 5.** Example of a patient with different distribution of emphysema between the right and left lungs.


