Quantitation of Emphysema by Computed Tomography Using a "Density Mask" Program and Correlation with Pulmonary Function Tests*

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We used a CT program "density mask" outlining areas with attenuation values less than -910 HU, to indicate areas of emphysema on a chest CT and to provide an overall percentage of lung involvement by emphysema. The "density mask" quantitation of emphysema was previously shown to correlate well with the pathologic assessment of emphysema in patients undergoing lung resection. We compared the CT quantitation of emphysema with mean lung density, overall lung volume on CT and pulmonary function tests in 85 patients. There was a significant correlation between the extent of emphysema on CT and FEV1/FVC percent of predicted, functional residual capacity percent predicted and Dsb percent predicted. Determination of the percentage of lung with areas of low attenuation by CT provides a useful method for quantitating emphysema in life and correlates significantly with pulmonary function tests.

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Emphysema is defined as "a condition of the lung characterized by abnormal permanent enlargement of the airspaces distal to the terminal bronchioles, accompanied by destruction of their walls, and without obvious fibrosis." Computed tomography has been shown to be a sensitive technique in evaluating the presence and severity of emphysema. On CT, emphysema is characterized by the presence of areas of abnormally low attenuation. Recently, Müller et al. used a GE 9800 CT scanner computer program "density mask" to outline and quantitate areas of emphysema on CT. Using this technique, they found that areas with attenuation of less than -910 HU on CT scan correlated closely with the pathologic assessment of emphysema on the corresponding slice of the resected lung specimens (r = 0.90). The method also allows objective quantitation of the overall lung volume on CT, as well as the percentage of lung with emphysema.

In this study, we used the CT "density mask" program in 85 patients to quantify the overall extent of emphysema in both lungs and correlated the CT quantitation of emphysema with pulmonary function tests. Twenty-five of these 85 patients were included in the original description of the "density mask" method to assess emphysema.  

METHODS

We studied 85 patients, 52 males and 33 females, ranging in age from 40 to 78 years (mean age ± SD = 64 ± 8 yr). They were selected from patients tested in the Vancouver General Hospital Pulmonary Function Laboratory during investigation for suspected malignancy. Patients with tumors were included if the tumor was peripheral and less than 7 cm in diameter or central but obstructing one segment or less. The limit for a peripheral lesion of 7 cm in diameter was chosen since the volume of a spherical lesion 7 cm in diameter would be only 180 ml, while obstruction of one segment would affect only about 1/20th of the lung volume. Thus, both types of lesions would be expected to have a negligible effect on lung function. We excluded patients with previous lung surgery, evidence of interstitial lung disease, pleural disease, pneumonia or previous history of congestive heart failure or tuberculosis.

Density Mask

All patients had CT of the chest as part of their investigation. The "density mask" was obtained as previously described. Briefly, the CT scans were obtained on a GE 9800 scanner at 10-mm intervals using 10-mm collimation. The CT scans were obtained during breath holding at end inspiration. Hard-copy images were photographed at a 1,500-HU window width and -600-HU window level. The "density mask" software program of the GE 9800 scanner was used to highlight on each slice voxels with attenuation values less than -910 HU, which were taken to indicate areas of emphysema as shown previously. The "density mask" program also automatically gave the total area and the area of the highlighted voxels for each slice (Fig 1), as well as the overall density of each slice. As each CT slice is 1-cm thick, the volume of each slice is equal to the area in cm² × the 1-cm thickness. Therefore, one can obtain the overall CT lung volume from the sum of the volumes of all slices. Similarly,
Table 1—CT Density Mask Results

<table>
<thead>
<tr>
<th></th>
<th>Mean ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean density (HU)</td>
<td>−794.0 ± 45.0</td>
<td>−652, −884</td>
</tr>
<tr>
<td>CT lung volume cm³</td>
<td>4,566.0 ± 1,329.0</td>
<td>1,941, 7,573</td>
</tr>
<tr>
<td>Volume of emphysema cm³</td>
<td>332.6 ± 563.3</td>
<td>0.1, 3,274</td>
</tr>
<tr>
<td>Overall percent of emphysema</td>
<td>6.52 ± 9.80</td>
<td>0, 54.3</td>
</tr>
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</table>

<0.50% (n = 25) | 0.17 ± 0.13 |
0.50-0.99% (n = 11) | 0.69 ± 0.14 |
1.00-4.99% (n = 17) | 2.7 ± 1.4 |
5.00-9.99% (n = 14) | 7.7 ± 1.6 |
≥10.00% (n = 18) | 21.6 ± 11.6 |

Statistical Analysis

We used linear regression analysis to determine the correlation between the "density mask" results and different parameters of lung function. Analysis of variance was used to evaluate differences in lung function results between groups with different extent of emphysema as quantitated by the CT "density mask" program.

RESULTS

The CT "density mask" results for both lungs are summarized in Table 1, which shows mean lung density, total CT lung volume, total volume of emphysema, and percentage of lung with emphysema. There was good correlation between the mean lung density and each of the following: total CT lung volume, total CT volume of emphysema and percentage of lung with volumes measured in a constant-volume body plethysmograph according to the technique of Du Bois and associates, using at least three determinations which were within 5% of each other; the mean value was used. In 18 patients, lung volumes were determined by both helium dilution and plethysmography.

Spirometric values were expressed as percent predicted using the prediction equations of Crapo and co-workers. Expiratory flows rates from the flow volume curve were expressed as percent of predicted according to the equations of Knudson and co-workers.

Predicted values for Dsb and the Dsb/Vx ratio were based on the prediction equations of Miller and co-workers for nonsmokers. Lung volumes were expressed as percent predicted based on the equations of Crapo and co-workers.

Figure 2. Relationship between mean lung density on CT and the percentage of lung involvement by emphysema on the CT density mask program. There was a significant correlation (r = −0.67, p < 0.001). However, there was overlap in mean lung density between cases without emphysema and cases with significant emphysema.

Pulmonary Function Tests

All patients had spirometry and expiratory flow rates measured on a rolling seal spirometer (PK Morgan equipment, Chatham, Kent, England), according to standard techniques. Single-breath diffusing capacity for CO was determined using an automated valve and timing device, and a bag in a box system (PK Morgan). A breath-holding time of about 10 s was used and was determined by the Jones and Meade method. The washout volume was 900 ml and the alveolar sample volume was 900 ml. At least two determinations of Dsb that were within 5% of each other were determined; the highest value was reported. In 11 patients (seven men and four women), whose hemoglobin level was reduced below 13 g/100 ml for men and 12 g/100 ml for women, Dsb was corrected for hemoglobin according to the method of Cotes and co-workers.

Fifty-seven subjects had lung volumes measured by the closed circuit helium dilution technique. Forty-six subjects had lung

Figure 1. Panel A: CT scan with right and left lungs outlined to measure lung area. The computer program indicates that the right lung area is 106.6 cm² and the left lung area, 103.7 cm². Since the CT slice is 1-cm thick, the lung volume at this level = sum of the right and left lung areas × 1 cm = 210.5 cm³. By adding all the CT images, the total lung volume can be calculated. Panel B: The "density mask" program outlines regions with attenuation < −910 HU to indicate emphysema and gives the area in cm² being outlined. The area of emphysema on the right is 53.8 cm² and on the left is 20.5 cm². The volume of lung with emphysema in this slice = sum of the right and left areas of emphysema × 1 cm thickness = 74.3 cm³. By adding all the CT images, the total lung volume with emphysema can be determined.

The volume of lung with emphysema can be determined from the sum of the volumes of all highlighted voxels for all slices. This, expressed as a percentage of the overall CT lung volume, gives the overall percentage of emphysema in both lungs. The mean overall lung density was calculated by adding the sum of the products of mean density and volume of each slice, and dividing that sum by the overall lung volume of all slices.

Quantification of Emphysema by CT (Kinsella et al)
emphysema (all absolute r values = 0.66 to 0.67, p<0.001). The correlation between mean lung density and percentage lung involvement with emphysema by CT is shown in Figure 2. The total CT lung volume showed significant correlation with total volume of emphysema (r = 0.50, p<0.001) and with percentage of lung with emphysema (r = 0.43, p<0.001). As expected, there was a very high correlation (r = 0.983, p<0.001) between the total volume of emphysema and the percentage of lung involved by emphysema.

The distribution of the CT extent of emphysema expressed as percentage of total lung volume among the 85 subjects is shown in Table 1. Twenty-five patients had minimal or no emphysema on CT (<0.5 percent of total lung volume), 14 had “mild” emphysema (≥5 percent and <10 percent), and 18 had “moderate or severe” emphysema affecting more than 10 percent of the total lung volume on CT.

The pulmonary function data are summarized in Table 2. Mean values for FEV₁, FVC, and FEV₁/FVC are close to normal but there was mild reduction in flow rates at low lung volumes (FEF25–75% and FEF50%), suggesting a mild degree of airflow obstruction. Mean values for Dsb and Dsb/VA also were slightly reduced. However, there were several patients with abnormalities in FEV₁, flow rates, lung volumes and diffusing capacity, as indicated by the SD and range in results. In the 18 patients who had lung volumes by both helium dilution and plethysmography, there was good correlation between the two determinations, with r = 0.90 for TLC. However, as expected in the presence of airflow obstruction and emphysema, plethysmographic TLC was slightly higher than helium TLC (mean ± SD = 6.73 ± 1.27 L vs 6.25 ± 1.33 L, p<0.001). The pulmonary function results were related to the extent of emphysema by comparing them in the five groups of patients divided as described previously according to the percentage of lung involved with emphysema (Table 3). There was no significant difference in age among the five groups (p>0.20). Pulmonary function tests assessing airflow (FEV₁, FEF50%) and diffusing capacity (Dsb and Dsb/VA) were significantly lower in the groups with increasing extent of emphysema than in the group with less than 0.5 percent emphysema (p<0.001).

Table 3—Lung Function Data According to CT Overall Percentage of Emphysema*  

<table>
<thead>
<tr>
<th>% of Emphysema</th>
<th>Range</th>
<th>Median</th>
<th>0.14</th>
<th>0.65</th>
<th>2.28</th>
<th>8.01</th>
<th>19.61</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cases</td>
<td>25</td>
<td>11</td>
<td>17</td>
<td>14</td>
<td>18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age, yr</td>
<td>62.5±8.1</td>
<td>63.0±9.3</td>
<td>62.2±8.5</td>
<td>64.7±7.4</td>
<td>67.6±5.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of emphysema</td>
<td>0.17±0.13</td>
<td>0.69±0.14</td>
<td>2.7±1.4</td>
<td>7.7±1.6</td>
<td>21.6±11.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEV₁ % predicted</td>
<td>94±18</td>
<td>88±14</td>
<td>89±23</td>
<td>59±23</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEV₁/FVC % predicted</td>
<td>99±9</td>
<td>91±8</td>
<td>88±12</td>
<td>84±14</td>
<td>61±15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEF50 % predicted</td>
<td>90±37</td>
<td>60±26</td>
<td>59±34</td>
<td>25±18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dsb % predicted</td>
<td>87±20</td>
<td>78±24</td>
<td>75±18</td>
<td>53±16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dsb/VA % predicted</td>
<td>91±20</td>
<td>79±16</td>
<td>73±19</td>
<td>73±18</td>
<td>55±14</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Data shown are Mean ± SD
Table 4—Correlation Coefficients between CT Scan Data and Lung Function Tests

<table>
<thead>
<tr>
<th></th>
<th>CT Total, Volume</th>
<th></th>
<th>CT mean Density</th>
<th></th>
<th>CT % of Emphysema</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r</td>
<td>p</td>
<td>r</td>
<td>p</td>
<td>r</td>
</tr>
<tr>
<td>FEV₁, % predicted</td>
<td>-0.28</td>
<td>&lt;0.01</td>
<td>0.44</td>
<td>&lt;0.001</td>
<td>-0.56</td>
</tr>
<tr>
<td>FEV₁/FVC % predicted</td>
<td>-0.49</td>
<td>&lt;0.001</td>
<td>0.85</td>
<td>&lt;0.001</td>
<td>-0.72</td>
</tr>
<tr>
<td>FEF₂₅₋₇₅ % predicted</td>
<td>-0.38</td>
<td>&lt;0.001</td>
<td>0.55</td>
<td>&lt;0.001</td>
<td>-0.51</td>
</tr>
<tr>
<td>Helium FRC % predicted</td>
<td>0.61</td>
<td>&lt;0.001</td>
<td>-0.55</td>
<td>&lt;0.001</td>
<td>0.35</td>
</tr>
<tr>
<td>Helium RV % predicted</td>
<td>0.46</td>
<td>&lt;0.001</td>
<td>-0.42</td>
<td>&lt;0.0005</td>
<td>0.48</td>
</tr>
<tr>
<td>Helium TLC % predicted</td>
<td>0.49</td>
<td>&lt;0.001</td>
<td>-0.33</td>
<td>&lt;0.01</td>
<td>0.32</td>
</tr>
<tr>
<td>Dsb % predicted</td>
<td>0.04</td>
<td>NS</td>
<td>0.29</td>
<td>&lt;0.005</td>
<td>-0.53</td>
</tr>
<tr>
<td>Dsb/VA % predicted</td>
<td>-0.16</td>
<td>NS</td>
<td>0.36</td>
<td>&lt;0.001</td>
<td>-0.53</td>
</tr>
</tbody>
</table>

Table 4 compares linear regression coefficients for various lung function tests with the CT total lung volume, mean lung density and percentage of emphysema. The mean lung density showed a significant correlation with indices of airflow (FEV₁, FEV₁/FVC, FEF₂₅₋₇₅%, FEF₅₀%), with lung density decreasing with decrease in flow rates. There was a good correlation between lung density and lung volumes whether measured by helium dilution or by plethysmography, with lung density decreasing with increasing lung volume. However, mean lung density was not significantly correlated with vital capacity. As expected, the CT total lung volume showed a significant correlation with flow rates, and helium dilution and plethysmographic lung volumes, being higher in subjects with lower flow rates and higher in subjects with higher volumes. The highest correlation of total CT lung volume was with helium dilution FRC expressed in liters (r = 0.81 p<0.001) (Fig 3). Total CT lung volume was not significantly correlated with either Dsb or Dsb/VA.

The extent of emphysema on CT as indicated by the percentage of emphysema showed a significant negative correlation with flow rates and Dsb and a significant positive correlation with lung volumes as shown in Table 4. The highest correlation was with FEV₁/FVC percent predicted. The extent of emphysema was significantly correlated with both Dsb and Dsb/VA (Fig 4). Only seven out of 36 patients with less than 1 percent emphysema had Dsb or Dsb/VA < 60 percent of predicted, while in most (13 out of 18) of the patients with > 10 percent emphysema, Dsb and Dsb/VA were reduced below 60 percent of predicted. The limit of 60 percent predicted for Dsb/VA discriminated better than Dsb patients with < 1 percent of emphysema from those with > 10 percent emphysema.

Table 5 shows the number of subjects with abnormal values for Dsb and Dsb/VA as defined by using the lower 95 percent confidence limit of normal from the prediction equations. The table allows us to analyze abnormality in Dsb by reference to the group with < 0.5 percent emphysema on CT. Based on the CT ‘density mask’ diagnosis of emphysema, we found that 14 out of the 18 cases with > 10 percent emphysema and 32 of the 60 cases with > 0.5 percent emphysema had abnormal Dsb values, while only seven of the 25 cases with < 0.5 percent had abnormal Dsb values, a highly significant difference by chi-square (p<0.001). Analysis of the Dsb/VA data suggested that it discriminated better than Dsb between the presence and absence of emphysema on CT. There were only four out of 25 cases with abnormal Dsb/VA.
TABLE 5—Number of Cases with Abnormal* Diffusing Capacity According to CT Overall Percentage of Emphysema

<table>
<thead>
<tr>
<th>CT % Emphysema</th>
<th>&lt;0.50</th>
<th>0.50-0.99</th>
<th>1.00-4.99</th>
<th>5.00-9.99</th>
<th>&gt;10.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>n = 25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dsb % predicted</td>
<td>7</td>
<td>4</td>
<td>4</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Dsb/VA % predicted</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td>6</td>
<td>17</td>
</tr>
</tbody>
</table>

*Abnormal is defined as being below the lower 95 percent confidence limit of normal from the prediction equations.

in the patients with < 0.5 percent emphysema, while Dsb/VA was abnormal in 35 out of 60 cases with > 0.5 percent emphysema, and in 17 out of 18 cases with > 10 percent emphysema (p<0.001 by chi-square analysis).

**Discussion**

In this study we used the CT “density mask” program to quantitate areas with attenuation values less than −910 HU which were taken to represent areas of emphysema,10 and to provide an overall percentage of lung involvement by emphysema. The CT quantitation of emphysema was correlated with mean lung density, overall lung volume and with commonly performed pulmonary function tests that are affected in emphysema.

The mean lung density was found to correlate well both with the total CT lung volume and with the percentage of lung with emphysema. Lung size increases in the presence of both emphysema and hyperinflation. Pathologic-physiologic correlative studies have shown a good correlation between pathologic extent of emphysema and lung size as indicated by TLC.10 Thus, one would expect a good correlation between the extent of emphysema on CT and CT lung volume. As the extent of emphysema increases, the total lung size increases due to overinflation and due to lung destruction with dilatation of terminal airspaces, resulting in a decrease in lung density (ie, attenuation values closer to that of air which is −1,000 HU). Mean lung density is dependent not only on the presence of emphysema, but also on the presence of airflow obstruction with hyperinflation which would result in a reduction in overall lung density even in the absence of emphysema. Goddard and co-workers5 also found that mean lung density decreased with hyperinflation in the absence of emphysema. The presence of a mass with high attenuation values did not significantly affect mean density since the mean density of slices with masses greater than 2 cm was recalculated to exclude the effect of the mass on the recorded mean attenuation. We excluded patients with masses greater than 7 cm in diameter which would have a volume of about 180 ml for a spherical lesion, an insignificant volume compared with the volume of both lungs.

While there is a good correlation between mean density and extent of emphysema (r = 0.55, p<0.001), there is a large scatter about the regression line. Mean lung density did not distinguish clearly cases without significant emphysema from cases with ≥ 5 percent emphysema. Our finding that mean lung density is not a good indicator of the presence or absence of emphysema is in agreement with previous investigators,5,8 who were not successful in attempting to assess emphysema by measuring the mean attenuation of the lung parenchyma. Extensive emphysema must be present to decrease mean lung density significantly.

There are several limitations to the measurement of density on CT which have been reviewed by Zerhouni and colleagues8 and summarized by Müller and co-workers.10 Measurements of density are affected by patient size, location and environment of the area being assessed, type of CT scanner, kilovoltage and reconstruction algorithm. However, in spite of these theoretical limitations, Müller et al10 found that using an attenuation value to diagnose emphysema was as reliable as the visual assessment. This is not surprising because the visual measurement of emphysema is based on the presence of localized areas of low attenuation which differ considerably from the remaining parenchyma and therefore can be reliably quantitated by the “density mask” program. Use of the threshold value also has the advantages of eliminating inter- and intra-observer variability and allowing accurate determination of the percentage of lung parenchyma with emphysema.

As expected, there was a good correlation between the CT lung volume and pulmonary function measurements of lung volume. The best correlation was with FRC (in liters) by either the helium dilution method (r = 0.81, p<0.001, n = 57), or the plethysmographic method (r = 0.79, p<0.001, n = 46). This is because the CT was obtained with the patients supine after submaximal inspiration, while helium dilution and plethysmographic lung volumes were obtained with patients in the sitting position. Because of the decrease in FRC with the supine position, and the submaximal inspiration used during CT, lung volume using CT would be expected to correspond more closely with FRC rather than with TLC with the sitting position. Since CT lung volume was not adjusted for differences in the size of the chest wall, it was measured as the CT volume with supine patients in a sitting position using the CT measurement of lung volume and supine measurements of TLC and FRC. These measurements were then compared to measurements of TLC and FRC obtained with the patients supine. The best correlation was with TLC (r = 0.79, p<0.001, n = 46) and FRC (r = 0.79, p<0.001, n = 46).

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in body size, it correlated better with absolute lung volumes than volumes expressed as percent predicted. The CT overall lung volume was found to correlate with tests of airflow (FEV₁, FEV₁/FVC, FEF50%), with CT lung volume increasing as flow rates decreased. This would be expected since reduction in airflow is known to be accompanied by hyperinflation and an increase in lung volumes on pulmonary function tests.

The percentage of lung with emphysema by CT "density mask" quantitation correlated inversely with indices of airflow FEV₁, FEV₁/FVC (Fig 4), FEF50%, and with diffusing capacity, expressed both as Dsb percent predicted and as a Dsb/VA ratio percent predicted. Our findings agree with those in a previously reported study from our institution by Morrison and co-workers who found correlations of −0.50 to −0.55 between Dsb and Dsb/VA and the extent of emphysema determined either by pathologic assessment of resected lung or by a visual CT score. We found a better correlation between FEV₁ and FEF50% and the extent of emphysema measured by the CT density mask (r = −0.51 to −0.56) than Morrison and colleagues when they assessed the extent of emphysema by a visual CT score (r = −0.34). This may be because the visual overall CT score used by Morrison and co-workers may not quantitate as precisely mild degrees of emphysema as the "density mask." There were no significant differences in the correlations between FEV₁ and FEF50% and the extent of emphysema when assessed by the CT "density mask" in this study, when compared with the correlations (−0.54 to −0.50) obtained with pathologic assessment of emphysema.

There were 11 patients in our study with an abnormal Dsb who had no significant emphysema (<1 percent) by CT "density mask" (Table 4); however, three of these patients had a normal Dsb/VA. This suggests that a Dsb/VA ratio discriminates better between the presence or absence of emphysema than Dsb. In these three patients, the single-breath alveolar volume during the Dsb test was significantly reduced resulting in a low Dsb with a normal Dsb/VA ratio and could explain the abnormal Dsb in these patients with no significant emphysema on CT "density mask." However, there were still eight subjects with abnormally low Dsb and Dsb/VA, which may be due to the CT underestimating or missing mild emphysema. Careful visual inspection of the CT revealed that all these patients had less than 1 percent emphysema which was correctly indicated by the "density mask." Müller et al pointed out that CT may miss mild emphysema; this is not a deficiency of the "density mask" program itself since the mild emphysema in these cases was also missed by careful visual assessment of the CT slices by two independent observers.

Localized areas of emphysema less than 0.5 cm in diameter often cannot be seen on CT. None of these subjects had prior chest radiation, chemotherapy, congestive heart failure, tuberculosis or evidence of interstitial lung disease, pneumonia or pleural disease, which could affect Dsb. If the patient was anemic, then Dsb was corrected for the effect of anemia by the method of Cotes and colleagues. Although some of our patients were current smokers, they refrained from smoking prior to the tests, so it is unlikely that the reduced Dsb could be due to the effects of carboxyhemoglobin which reduces Dsb by about 1 percent for each 1 percent carboxyhemoglobin. Thus, it is unlikely that the reduced Dsb is due to other causes. Therefore, we conclude that the low Dsb, in eight of our subjects with <1 percent emphysema, is probably due to emphysema being missed or underestimated by CT.

In a recent report Sakai and co-workers correlated pulmonary function tests with the extent of emphysema using a CT score determined both by direct observation and by a grid method in 30 subjects. Their correlations between the extent of emphysema and pulmonary function are similar but a little higher than those in the present study. This is perhaps due to their use of a four-point scale combining the extent and severity of emphysema, whereas we assessed the extent of emphysema based on the actual percentage of lung involved (ie, a 100-point scale). They also appear to have had a larger proportion of subjects with more severe emphysema than in our study. Ten of their 30 subjects (33 percent) had "moderate" emphysema, and six of 30 (20 percent) had "severe" emphysema as assessed by CT, while 17 of 85 (20 percent) of the patients in the present study had >10 percent of the lung involved by emphysema, and nine of 85 (11 percent) had >20 percent emphysema. They also did not have any subjects with 0 score of emphysema, whereas 25 of 85 (29 percent) of our patients had emphysema involving <0.5 percent of the overall lung area, which probably roughly corresponds to an emphysema score of 0 on visual assessment.

It was shown previously that the "density mask" is an accurate method for quantitating the extent of emphysema. This study shows that the parameters of lung function usually affected by the presence of emphysema are correlated with the CT "density mask" extent of emphysema, showing increasing abnormality with increasing extent of emphysema on CT. Most studies comparing lung function with the extent of emphysema rely on a pathologic assessment of emphysema. Pathologic evaluation remains the gold standard for assessment of emphysema since emphysema is defined in pathologic terms. However, in studies of physiologic-pathologic correlations performed in patients undergoing lung resection, pathologic assess-
ament of emphysema is based on one lung or often on one lobe, neither of which may accurately reflect the overall extent of emphysema in both lungs. The CT "density mask" program, on the other hand, gives an objective quantitative assessment of the overall extent of emphysema in both lungs. Despite missing mild degrees of emphysema, it provides a useful technique for quantitating the overall extent of emphysema in life.

REFERENCES

10 Miller NL, Staples CA, Miller RR, Abboud RT. "Density mask": an objective method to quantify emphysema using computed tomography. Chest 1988; 94:782-87