Air trapping window: an appropriate narrow window setting of inspiratory high-resolution CT in the diagnosis of small airway disease

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Aims and objectives

Purpose

Small airway disease has a wide variety of etiologies such as infectious, inflammatory, and fibrotic bronchiolitis. The airway abnormality involves the bronchiolar level and beyond. The imaging findings of small airway disease can be direct sign which include centrilobular branching nodules, peribronchiolar ground-glass opacities, and bronchiolectasis and indirect signs which include mosaic attenuation and air trapping (1).

Expiratory high-resolution CT (HRCT) has becomes the important role in the detection of air trapping by increasing the difference of lung attenuation between normal lung and air trapping region (1-5). However, lobular and segmental air trapping may appreciable on inspiratory HRCT as a mosaic attenuation pattern (1).

The important problem might effects the detection of air trapping in the inspiratory HRCT is the low contrast difference between subtle decreased lung attenuation and normal lung parenchyma (6) in the routine lung window setting (a window width of 1500 HU, a window level of -700 HU) (7).

We hypothesize that the narrow lung window setting may increasing contrast difference between normal lung and air trapping region. Expiratory HRCT may be not added diagnostic utility for diagnosis of small airway disease.

Thus, the purpose of our retrospective study was to evaluate the ability of a narrow lung window setting to identify an air trapping in patients with clinically suspected small airway disease.

Methods and materials

Selection of cases

This retrospective study was approved by the institutional review board and was HIPPA-compliant. The informed consent was waived.

We identified 63 consecutive patients with clinically suspected small airway disease and had CT obtained at the University of Washington Medical Center between January, 2011, and August, 2011, using keyword search terms of air trapping and small airway disease. All of the images were assessed by a chest radiologist (W.S., with 7 years of experience in CT) in detecting air trapping for the diagnosis of small airway disease. Twenty-nine (46%) patients were excluded due to no available HRCT or no expiratory scan. There
were final thirty-four patients who had HRCT scans for evaluation. Figure 1 shows the case selection flowchart.

**HRCT**

HRCT were obtained on GE scanners: LightSpeed Qx/I, LightSpeed Ultra, and HiSpeed scanners and Discovery CT750HD (GE Medical Systems, Waukesha, WI). Supine inspiratory scans were performed using collimation of 1.25 mm, section interval of 10 mm, 120 kV, and 100-200 mAs. Supine expiratory scans using collimation of 1.25 mm, section interval of 20 mm, 120 kV, and 100-200 mAs were obtained. Prone inspiratory scans using collimation of 1.25 mm, section interval of 20 mm, 120 kV, and 100-200 mAs were performed.

Inspiratory HRCT images were reviewed in the narrow lung window setting with a window level ranged from -750 to -850 HU and a window width ranged from 200 to 400 HU. All of these window levels were in between the typical normal lung attenuation (-730 HU) and advanced emphysematous lung attenuation (-950 HU) (8). In addition, all of these window widths were included the entire range of grey scale. There were final five narrow lung window settings for reviewing in three axial plains including aortic arch, carina, and diaphragm levels. Figure 2 shows example of five narrow lung window settings.

**Image interpretation**

Five image sets of all 34 HRCT scans were randomized and reviewed by five readers who were blind to the clinical information. The five readers with a range of experience include two radiology resident physicians (R.M.E., T.D.T., with 2 and 3 years of experience in CT), and three thoracic radiologists (S.D., G.A.K., S.N.P., with 11, 10 and 11 years of experience in CT, respectively).

The evaluation of HRCT was performed in five separate interpretation sessions with different narrow lung window settings. At least a 1-week interval separated of these sessions. All images sets were scored in confidence of detection of air trapping, using a four-point ordinal scale with 1 representing "definitely not present", 2 representing "likely not present", 3 representing "likely present", and 4 representing "definitely present". A score of 1-2 were interpreted as negative result and score 3-4 were interpreted as positive result.

The estimated effective dose (E) to the patients during HRCT scans were calculated by using the formula; \( E = \text{dose-length product (DLP)} \times \text{conversion factor} \) (9, 10).

**Statistical Analysis**

Statistical analysis was performed using STATA version 10.1 (Stata Corporation, College Station, TX). Receiver operating characteristic (ROC) analysis was used to evaluate
ability of narrow lung window settings in identifying air trapping. Sensitivity, specificity, positive and negative likelihood ratios, diagnostic odd ratio, positive and negative predictive values, and accuracy were calculated.

Comparison of image interpretation of narrow lung window settings of all readers and conventional expiratory scan was analyzed by using chi-square test or Fisher's exact test (for non-normally distributed variables). Two-tailed p values less than 0.05 were considered statistically significant.

Inter-reader agreement in different narrow lung window settings was assessed with Cohen's Kappa Coefficient for detecting air trapping. A Kappa value of < 0.20 indicated poor agreement; 0.21-0.40, fair agreement; 0.41-0.60, moderate agreement; 0.61-0.80, good agreement; 0.81-1.00, very good agreement (11).

Images for this section:
**Eligible Patients**
63 patients who had clinically suspected small airway disease and had CT were reviewed by a radiologist

29 patients were excluded due to no available HRCT or no expiratory scan

All HRCT images including inspiratory and expiratory scans of 34 patients were reviewed by a radiologist in identifying of air trapping.

**Final population**
34 patients (No air trapping in 16 patients, presence of air trapping in 18 patients)

Five narrow lung window settings from the inspiratory scan were reviewed separately by five readers

Fig. 1: The case selection flow chart.
Fig. 2: Example for the image sets for five separate interpretation sessions. First session was done with a window width of 200 HU and a window level of -750 HU. Second session was done with a window width of 200 HU and a window level of -800 HU. Third session was done with a window width of 300 HU and a window level of -800 HU. Forth session was done with a window width of 400 HU and a window level of -800 HU. Fifth session was done with a window width of 400 HU and a window level of -850 HU.
Results

Of the 34 patients, there were 19 men (55.9%) and 15 women (44.1%), and ages ranged from 16 to 77 years with a mean of 48.6 years.

The expiratory HRCT diagnosis of all 34 patients showed no air trapping in 16 (47.1%) patients and presence of air trapping in 18 (52.9%) patients.

The underlying disease of all 34 patients included constrictive bronchiolitis in 8 (23.6%) patients, usual interstitial pneumonia in 8 (23.6%) patients, cystic fibrosis in 7 (20.5%) patients, sarcoidosis in 3 (8.8%) patients, hypersensitivity pneumonitis in 2 (5.9%) patients, graft-versus-host disease in 2 (5.9%) patients, collagen vascular disease in 2 (5.9%) patients, Wegener’s granulomatosis in 1 (2.9%) patient, and asthma in 1 (2.9%) patient.

The mean of estimated effective dose during expiratory HRCT scan was 0.3 millisievert (mSv) and total HRCT scan was 5.5 mSv. The mean of percentage of estimated effective dose during prone HRCT scan to total scan was 7.3%.

The patient characteristics, expiratory HRCT diagnosis, and the estimated effective dose to the patients during HRCT are shown in Table 1.

A narrow lung window with a window width of 300 HU and a window level of -800 HU provided a sensitivity of 82% (95%CI: 73, 89), a specificity of 84% (95%CI: 74, 91), a PPV of 85% (95%CI: 76, 92), a NPV of 81% (71, 89), an accuracy of 83% (95%CI: 76, 88), and an area under the ROC curve of 0.830 (95%CI: 0.773, 0.887, p = 0.000) in detecting air trapping. The comparison of diagnostic performance between five narrow lung window settings in the identifying air trapping is shown in Table 2. The comparison of accuracy in detecting air trapping of all five readers between five narrow lung window settings is shown in Table 3.

The inter-reader agreement for detecting air trapping ranged from fair to good agreement with a Kappa coefficient ranged from 0.203-0.624. The inter-reader agreement is shown in Table 4.

Images for this section:
### Patient characteristic N=34

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age: years, mean (SD)</td>
<td>48.6 (18.3)</td>
</tr>
<tr>
<td>Gender: number, (%)</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>19 (55.9)</td>
</tr>
<tr>
<td>Female</td>
<td>15 (44.1)</td>
</tr>
<tr>
<td>Expiratory HRCT diagnosis: number, (%)</td>
<td></td>
</tr>
<tr>
<td>No air trapping</td>
<td>16 (47.1)</td>
</tr>
<tr>
<td>Presence of air trapping</td>
<td>18 (52.9)</td>
</tr>
<tr>
<td>Underlying disease</td>
<td></td>
</tr>
<tr>
<td>Constrictive bronchiolitis</td>
<td>8 (23.6)</td>
</tr>
<tr>
<td>UIP</td>
<td>8 (23.6)</td>
</tr>
<tr>
<td>Cystic fibrosis</td>
<td>7 (20.5)</td>
</tr>
<tr>
<td>Sarcoidosis</td>
<td>3 (8.8)</td>
</tr>
<tr>
<td>Hypersensitivity pneumonitis</td>
<td>2 (5.9)</td>
</tr>
<tr>
<td>GVHD</td>
<td>2 (5.9)</td>
</tr>
<tr>
<td>Collagen vascular disease</td>
<td>2 (5.9)</td>
</tr>
<tr>
<td>Wegener’s granulomatosis</td>
<td>1 (2.9)</td>
</tr>
<tr>
<td>Asthma</td>
<td>1 (2.9)</td>
</tr>
<tr>
<td>Estimated effective dose during HRCT to patients: mSv, mean (SD)</td>
<td></td>
</tr>
<tr>
<td>Helical scans</td>
<td>4.8 (2.6)</td>
</tr>
<tr>
<td>Expiratory scans</td>
<td>0.3 (0.1)</td>
</tr>
<tr>
<td>Prone scans</td>
<td>0.4 (0.1)</td>
</tr>
<tr>
<td>Total scans</td>
<td>5.5 (2.7)</td>
</tr>
<tr>
<td>% Expiratory/Total scans</td>
<td>7.3 (3.1)</td>
</tr>
</tbody>
</table>
Table 1: Patient characteristics, expiratory HRCT diagnosis, underlying disease, and estimated effective dose to the patients during HRCT (Note. SD = standard deviation; % = percentage; HRCT = high-resolution CT; mSv = millisievert; UIP = usual interstitial pneumonia; GVHD = graft-versus-host disease; % Expiratory/Total scans = percentage of estimated effective dose during expiratory scans to total scans)

<table>
<thead>
<tr>
<th>Window</th>
<th>Sensitivity (95%CI)</th>
<th>Specificity (95%CI)</th>
<th>ROC (95%CI)</th>
<th>LH+ (95%CI)</th>
<th>LH- (95%CI)</th>
<th>Odd (95%CI)</th>
<th>PPV (95%CI)</th>
<th>NPV (95%CI)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 W = 200 HU L = -750 HU</td>
<td>60 (49-70) 84 (74-91) 0.719 (0.654-0.784) 3.690 (2.180-6.240) 0.478 (0.364-0.626) 7.730 (3.750-15.900) 81 (69-89) 65 (55-74)</td>
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<td></td>
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</tr>
<tr>
<td>2 W = 200 HU L = -800 HU</td>
<td>81 (71-89) 78 (67-86) 0.793 (0.732-0.854) 3.600 (2.370-5.480) 0.244 (0.156-0.380) 14.800 (7.060-31.000) 80 (71-88) 78 (68-87)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 W = 300 HU L = -800 HU</td>
<td>82 (73-89) 84 (74-91) 0.830 (0.773-0.887) 5.060 (3.050-8.400) 0.212 (0.135-0.334) 23.800 (10.700-52.900) 85 (76-92) 81 (71-89)</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>4 W = 400 HU L = -800 HU</td>
<td>83 (74-90) 83 (72-90) 0.829 (0.772-0.886) 4.760 (2.930-7.730) 0.202 (0.126-0.324) 23.600 (10.600-52.200) 84 (75-91) 81 (71-89)</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>5 W = 400 HU L = -850 HU</td>
<td>78 (68-86) 83 (72-90) 0.801 (0.714-0.862) 4.440 (2.730-7.240) 0.269 (0.181-0.402) 16.500 (7.740-35.100) 83 (74-91) 77 (66-85)</td>
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</tbody>
</table>

Table 2: Comparison of sensitivity, specificity, receiver operating characteristic (ROC) analysis, positive and negative likelihood ratios, positive and negative predictive values of five narrow lung window settings in the detection of air trapping (Note. Numbers in parentheses are 95% confidence intervals (95%CI); ROC area = area under the receiver operating characteristic curve; LH+ = positive likelihood ratio; LH- = negative likelihood ratio; Odd = diagnostic odd ratio; PPV = positive predictive value; NPV = negative predictive value; W = window width; L = window level; HU = Hounsfield unit)

<table>
<thead>
<tr>
<th>Window</th>
<th>Reader 1 (Accuracy (95% CI) n)</th>
<th>Reader 2 (Accuracy (95% CI) n)</th>
<th>Reader 3 (Accuracy (95% CI) n)</th>
<th>Reader 4 (Accuracy (95% CI) n)</th>
<th>Reader 5 (Accuracy (95% CI) n)</th>
<th>All readers (Accuracy (95% CI) n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 W = 200 HU L = -760 HU</td>
<td>65 (47-80) 22/34 82 (66-93) 28/34 71 (53-85) 24/34 71 (53-85) 24/34 66 (50-83) 23/34 71 (64-78) 121/170</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>2 W = 200 HU L = -800 HU</td>
<td>77 (59-89) 26/34 82 (66-93) 28/34 82 (66-93) 28/34 74 (56-67) 25/34 82 (66-93) 28/34 79 (73-85) 139/170</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>3 W = 300 HU L = -800 HU</td>
<td>88 (73-97) 30/34 88 (73-97) 30/34 82 (66-93) 28/34 79 (62-91) 27/34 77 (59-89) 26/34 83 (76-88) 141/170</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 W = 400 HU L = -800 HU</td>
<td>88 (73-97) 30/34 94 (60-99) 32/34 79 (62-91) 27/34 79 (62-91) 27/34 74 (56-87) 25/34 83 (76-88) 141/170</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>5 W = 400 HU L = -850 HU</td>
<td>86 (59-86) 29/34 91 (76-88) 31/34 79 (62-91) 27/34 77 (59-89) 26/34 66 (50-83) 23/34 80 (73-86) 136/170</td>
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</tbody>
</table>

Table 3: Comparison of the accuracy in detecting air trapping of all five readers between five narrow lung window settings (Note. Numbers in parentheses are 95% confidence intervals (95%CI); % = percentage; n = number; W = window width; L = window level; HU = Hounsfield unit)
<table>
<thead>
<tr>
<th>Reader</th>
<th>Percentage of agreement</th>
<th>Kappa (95%CI)</th>
<th>Standard error</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 vs 2</td>
<td>80.41</td>
<td>0.624 (0.573-0.682)</td>
<td>0.067</td>
<td>0.000</td>
</tr>
<tr>
<td>1 vs 3</td>
<td>67.18</td>
<td>0.416 (0.345-0.459)</td>
<td>0.060</td>
<td>0.000</td>
</tr>
<tr>
<td>1 vs 4</td>
<td>57.59</td>
<td>0.282 (0.238-0.329)</td>
<td>0.052</td>
<td>0.000</td>
</tr>
<tr>
<td>1 vs 5</td>
<td>76.12</td>
<td>0.480 (0.394-0.495)</td>
<td>0.067</td>
<td>0.000</td>
</tr>
<tr>
<td>2 vs 3</td>
<td>73.88</td>
<td>0.506 (0.432-0.582)</td>
<td>0.067</td>
<td>0.000</td>
</tr>
<tr>
<td>2 vs 4</td>
<td>68.94</td>
<td>0.413 (0.349-0.504)</td>
<td>0.061</td>
<td>0.000</td>
</tr>
<tr>
<td>2 vs 5</td>
<td>72.29</td>
<td>0.465 (0.441-0.498)</td>
<td>0.063</td>
<td>0.000</td>
</tr>
<tr>
<td>3 vs 4</td>
<td>74.06</td>
<td>0.451 (0.324-0.460)</td>
<td>0.066</td>
<td>0.000</td>
</tr>
<tr>
<td>3 vs 5</td>
<td>59.82</td>
<td>0.312 (0.277-0.442)</td>
<td>0.053</td>
<td>0.000</td>
</tr>
<tr>
<td>4 vs 5</td>
<td>49.71</td>
<td>0.203 (0.195-0.217)</td>
<td>0.045</td>
<td>0.000</td>
</tr>
<tr>
<td>Overall</td>
<td>68.00</td>
<td>0.415</td>
<td></td>
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</tr>
</tbody>
</table>

*Table 4:* Inter-reader agreement in the detection of air trapping in five readers
Conclusion

Air trapping and mosaic attenuation pattern are the indirect signs of small airway disease which are the consequence from obstructed, narrowed, or obliterated bronchioles (1, 12). Air trapping may be detected by the presence of mosaic attenuation from inspiratory HRCT and is accentuated by the expiratory HRCT (13-15).

The diagnostic performance for detecting air trapping assessed in 34 patients with clinically suspected small airway disease was different in five narrow lung window settings performed in the inspiratory images. By ROC analysis, we demonstrated the most appropriate narrow lung window at a window width of 300 HU and a window level of -800 HU with highest area under the ROC curve reflecting the potential ability to identify air trapping (Figure 3).

From our study, the sensitivity of this narrow lung window setting for detecting air trapping was 82%. It was better than 50% sensitivity of the ability for detecting low attenuation area of mosaic pattern from the study by Jensen et al (15). However, it was slightly lower than the 87% sensitivity of the conventional expiratory HRCT for detecting air trapping from the study by Sweatman et al (16).

There are some potential problems with inspiratory HRCT scan for identifying the large area of low lung attenuation representing a large area of air trapping such as lobar air trapping (1) without or minimal lung attenuation difference. It may cause false negative result (Figure 4). However, the negative predictive value of our narrow lung window setting for detecting air trapping was 81%. In addition, in some patients with lung parenchymal abnormalities such as emphysema or advanced lung fibrosis, may results in lung attenuation difference and mimic air trapping. It may cause false positive result (Figure 5-6). However, the positive predictive value of our narrow lung window setting for detecting air trapping was 85% and the mean accuracy was 83%. In the patient with highly suspicion of small airway disease and having of large area of low lung attenuation or questionable lung attenuation difference, conventional expiratory scan should be considered.

Inter-reader agreements quantified as Cohen's Kappa Coefficient were varied ranging from fair to good agreement. The explanation could be due to unfamiliar appearance of this high contrast narrow window setting which might effect to the reader's confidence in detecting air trapping.

The estimate effective dose to the patient during expiratory HRCT scan in our study was 0.3 mSv. It was 7.3% to the estimated effective dose of the total HRCT scan. This result may help to reduce an unnecessary scan and to decrease radiation exposure to the patient.
The limitations of our study are retrospective design. Another limitation is that only selected images were used for evaluation. The inability to view the entire study may decrease reader's confidence level. In addition, there was no clinical or pathologic correlation. Finally, there is no respiratory gating during HRCT for confirmation of the respiratory phases.

In conclusion, the ability of a narrow lung window setting from inspiratory HRCT for detecting air trapping is demonstrated, analogously to the routinely used "liver" and "bone" window settings (17, 18). In the patients with clinically suspected small airway disease, obtaining HRCT with using an air trapping window (a window width of 300 HU, a window level of -800 HU) may be sufficient for identifying air trapping in the inspiratory scan. Familiarity with this window setting may obviate the conventional expiratory scan and help to decrease an unnecessary radiation exposure.

Images for this section:
Fig. 3: A and B inspiratory and expiratory images (window width 1500, window level -700 HU) at the lower lung zone show mosaic attenuation pattern with multiple bilateral lobular air trapping. C and D narrow lung window settings from inspiratory images (C window width 200, window level -750 HU; D window width 300, window level -800 HU) show multiple air trapping. E and F coronal images (E window width 1500, window level -700 HU; F window width 300, window level -800 HU) show better visualization of the air trapping by using narrow lung window setting. The patient was a 29-year-old man with cystic fibrosis presented with dyspnea.
Fig. 4: A and B inspiratory and expiratory images (window width 1500, window level -700 HU) at the lower lung zone show focal area of air trapping at the right middle lobe. C and D narrow lung window settings from inspiratory images (C window width 200, window level -750 HU; D window width 300, window level -800 HU) show no detectable area of different lung attenuation to indicate air trapping. The patient was a 20-year-old man with graft-versus-host disease after bone marrow transplant presented with dyspnea.
**Fig. 5:** A and B inspiratory and expiratory images (window width 1500, window level -700 HU) at below the carina level show right more than left paraseptal emphysema without air trapping. C and D narrow lung window settings from inspiratory images (C window width 200, window level -750 HU; D window width 300, window level -800 HU) show multiple low attenuation areas and may mimic air trapping. The patient was a 68-year-old with COPD presented with shortness of breath.
Fig. 6: A and B inspiratory and expiratory images (window width 1500, window level -700 HU) at the aortic arch level show bilateral areas of lung fibrosis. C and D narrow lung window settings from inspiratory images (C window width 200, window level -750 HU; D window width 300, window level -800 HU) show multiple different lung attenuation areas and may mimic air trapping. The patient was a 71-year-old man with idiopathic pulmonary fibrosis presented with shortness of breath.
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