Demystifying Air Trapping

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Demystifying Air Trapping

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Financial Disclosure

We do not have any relationships to report with ACCME defined ineligible companies.

We will not be discussing unlabeled/investigational uses of medical devices or pharmaceuticals during this presentation.
Overview

• Utility and ambiguity of air trapping
• Literature review, including quantitative CT analysis
• Proposed algorithm to aid radiologists’ consistency and confidence
• Case examples
• Additional considerations in practice
Relevance

• Pulmonary function tests (PFTs) are not always sensitive to the detection of small airways disease.
  • Forced expiratory flow in mid-expiratory phase ($\text{FEF}_{25-75\%}$) is the most sensitive measure

• Imaging diagnosis of air trapping can only be made with expiratory scan as part of High-Resolution Chest CT (HRCT) protocol but can be rather subjective.
  • Lowest interobserver agreement among HRCT findings [1]
Relevance

- Air trapping has specific associations with a spectrum of small airways diseases:
  - Hypersensitivity pneumonitis
  - Bronchiolitis obliterans
  - Sarcoidosis
- In cases of inhomogeneous or mosaic attenuation, its presence can distinguish small airway from vascular etiology or ground-glass opacity.
Relevance

• Studies have historically shown strong correlations between quantitative CT analysis and PFT indicators of small airway disease as well as clinical outcomes.

• Translation of these objective findings from the research setting to the radiologist’s every-day practice has not been thoroughly explored thus far.
Background

• The expected attenuation of normally inflated lung (at total lung capacity) on inspiratory CT is \(-856\) HU. Normal lung parenchyma should increase beyond this value on expiratory CT.

• This threshold value on expiration has been widely accepted across the literature.

• Numerous quantitative techniques have been used together to assess air trapping, often in the context of determining COPD phenotype.
Expiratory CT

- Originated by Webb and colleagues in 1993
- Normal findings: decrease in cross-sectional lung area, reduction in airway caliber, and appropriate decrease in lung attenuation
- Adequacy of technique evaluated by bowing of posterior tracheal wall
- May reveal air trapping in the presence of normal inspiratory scan
- Should at least be incorporated in the initial HRCT assessment, if not routinely or on follow-up
Expiratory CT

Acquisition methods [2]

• Postexpiratory: after forced exhalation; scans at predetermined levels, set 2- to 4-cm intervals, or abnormal-appearing levels

• Dynamic expiratory: during forced exhalation; can be performed with reduced dose technique; may demonstrate greater attenuation increases

• Spirometrically triggered: at pre-determined volume of gas expired; useful in pediatric setting
Quantitative assessment

- **Threshold-based** methods: Percentage of lung voxels below a specific threshold, or within a certain range. A **density mask** can be generated to provide anatomic visualization.

- Original density mask study investigated emphysema, showing pathologic correlation with threshold value -950 HU [3].

- Schroeder et al reported correlation between percent lung less than -856 HU and spirometric small airway impairment in smokers, as well as GOLD stage in COPD patients [4].

- Busacker et al identified a subtype of severe asthmatics requiring hospitalization and mechanical ventilation by analyzing volume of lung less than -856 HU [5].
Quantitative assessment

• **E/I-MLD ratio (expiratory/inspiratory mean lung density):** Global measure. Greater degree of air trapping presents with higher ratio of mean lung density at expiration versus inspiration.

• Mets et al found this ratio outperformed threshold-based and voxel-to-voxel volume change methods in detecting air trapping in lung cancer screening patients, as measured by RV/TLC [6].

• In smokers, E/I-MLD showed stronger correlation than inspiratory HRCT measurements (reflecting emphysema) when compared with PFT indicators in a study by O'Donnell et al [7].
Quantitative assessment

- Voxel-to-voxel co-registration of inspiratory and expiratory imaging can be post-processed to generate anatomic maps.
- Galbán et al proposed a promising imaging biomarker to detect COPD phenotypes in a study that distinguished areas of small airway disease from emphysema using voxel-based post-processing [8].
- Solyanik et al used a similar voxel-based co-registration technique which performed as strongly as E/I-MLD for air trapping detection in post-lung transplant bronchiolitis obliterans [9].
Attenuation increase from inspiration to expiration

- **Air trapping index (ATI)**: Volume of voxels below a certain subtraction threshold, between inspiratory and expiratory CT.
- Kim et al showed strong correlation with ATI using threshold 50 HU compared to PFT indicators of small airway disease, as strong as E/I-MLD [10].
Attenuation increase from inspiration to expiration

- “Normal” attenuation difference can range anywhere from 80 to 300 HU.
- Healthy patients (128 HU) demonstrate a significantly larger difference between inspiration and expiration, when compared to ex-smokers (77 HU) and current smokers (67 HU) [2].
- In a study of COPD patients, Lee et al used E/I-MLD to find the best subtraction thresholds from inspiration to expiration for both RV/TLC and FEF$_{25-75\%}$. After plotting relationship between both, arrived at an optimum subtraction threshold of 60 HU [11].
Air trapping algorithm

Proposed algorithm to aid the radiologist’s confidence and consistency in diagnosing air trapping on HRCT.

- Small ROI’s 1-2 cm’s, avoid large vessels
- Try to exclude areas of emphysema

On expiratory scan with adequate technique, are there lobular lucent areas measuring less than -856 HU?

Air trapping present

Yes

No or not sure

Compare relatively lucent areas on inspiratory and expiratory scan at same location. Is increase in attenuation less than 60 HU?

Air trapping present

Yes

No air trapping

No
Inspiratory CT (left) appears normal (incidental esophageal diverticulum noted). Expiratory CT (right) demonstrates adequate technique (bowing of posterior trachea) and no lobular lucent areas measuring less than -856 HU. Density of a relatively lucent area in right upper lobe on expiratory scan is compared to the same location on inspiratory scan. Increase in attenuation is greater than 60 HU, confirming the absence of air trapping.
Inspiratory (left) and expiratory CT (right) in a patient with rheumatoid arthritis. Lobular areas of lucency measuring less than -856 HU are present in the right upper lobe on expiratory scan, indicating presence of air trapping. Less than 60 HU increase from inspiratory scan compared to expiratory scan is also present, confirming the finding. Presence of air trapping in this case suggests diagnosis of bronchiolitis obliterans.
Case 3

Patient with bronchiolitis in the setting of mycobacterium avium complex infection. Inspiratory scan (left) appears normal. Expiratory scan (right) demonstrates a lobular area of lucency in the left upper lobe laterally measuring less than -856 HU, indicating presence of air trapping. Less than 60 HU increase from inspiratory scan compared to expiratory scan is also present, confirming the finding.
Case 4

Mosaic attenuation is present on HRCT in a medically complicated patient with coronary artery disease presenting with dyspnea. Expiratory scan (right) reveals no lobular lucent areas measuring less than -856 HU and demonstrates an appropriate increase in attenuation (greater than 60 HU) compared to inspiratory CT (left). This indicates absence of air trapping. Subsequent PFT results were concordant and compatible with restrictive pattern.
Case 5

Inspiratory (left) and expiratory CT (right) in a patient with coronary artery disease and worsening dyspnea. Lobular lucent areas measuring less than -856 HU are present on expiratory scan and demonstrate less than 60 HU increase compared to inspiratory scan, indicating presence of air trapping. Mosaic attenuation at the lung bases is accentuated on expiratory imaging, interspersed with normal lung parenchyma (“head cheese” sign). Diagnosis of chronic hypersensitivity pneumonitis was suggested and was concordant with the patient’s PFT findings.
Case 6

Mosaic attenuation is present on inspiratory (top left) and expiratory (top right) CT. There is an attenuation increase of greater than 60 HU, indicating absence of air trapping. Inhomogeneous attenuation in this case is attributable to mosaic perfusion due to chronic pulmonary emboli (green arrow, bottom left), rather than air trapping.
“Normal” air trapping

• Limited air trapping may be seen in normal patients
  • Superior segments of lower lobes
  • Dependent aspects of the lungs

• Segmental (greater than three adjacent lobules) and lobar air trapping is highly suggestive of small airway disease.

• Anywhere up to 47-61% of asymptomatic patients with normal PFT’s have been shown to have air trapping on HRCT, although definitions vary across studies. [2]
Implications in emphysema

• COPD is a highly heterogenous disorder, with small airways disease and emphysema representing components of a disease spectrum.

• Wide variation in results and design (including or excluding emphysematous lung)
  • Matsuoka et al excluded emphysematous lung using -950 HU in their study of COPD patients [12].

• In the Mets et al study examining early small airway impairment in smokers in lung cancer screening program, whole lung E/I-MLD and an ATI using subtraction threshold 80 HU outperformed the Matsuoka method [6].
Takeaway points

• Air trapping has important diagnostic utility but can be rather subjective.

• Studies have shown strong correlations between quantitative CT analysis and PFT indicators of small airway impairment.
  • Often driven by characterizing COPD phenotypes

• We propose an algorithm that attempts to translate findings from the research setting to the radiologist’s every-day practice.

• Additional considerations (“normal”, relationship with emphysema, proper HRCT technique) can improve performance of our algorithm.
References

References

Thank You!