### COPD: Definition

- **COPD** is a *preventable and treatable* disease with some significant *extrapulmonary effects* that may contribute to the severity in individual patients.
- Its *pulmonary component* is characterized by *airflow limitation* that is *not fully reversible*.
- The airflow limitation is usually progressive and associated with an abnormal inflammatory response of the lung to noxious particles or gases.

[http://www.goldcopd.org](http://www.goldcopd.org)

### CT of COPD: From Morphology to Function

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#### Component 1: Emphysema

- Destruction of gas exchanging surface of the lung (respiratory bronchioles and alveoli) & capillary system
- Primary mechanism: imbalance of endogenous proteinase and antiproteinase
- Thin-section CT: area of decreased attenuation

#### Subtypes of Emphysema

* Depending on which part of the pulmonary acinus is primarily affected

<table>
<thead>
<tr>
<th>Component</th>
<th>Centriacinar (centrilobular)</th>
<th>Paracinar (Panlobular)</th>
<th>Distal acinar (Paraseptal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Affected</td>
<td>Smoking</td>
<td>Uniformly enlarged A1-A2 + Smoking</td>
<td>Affected</td>
</tr>
<tr>
<td>Spared</td>
<td></td>
<td></td>
<td>Upper Cystra, Bullae</td>
</tr>
</tbody>
</table>

#### CT – Pathology Comparison

- Comparison with Macroscopic and Microscopic Morphometry
  - 80 patients referred for surgical resection
  - 1 mm x 4 DCT
  - Comparison with macroscopically measured area and microscopic indexes of the resected lung
- Excellent correlation

Madani A, Gevenois PA, Radiology, 2006
Component 2: Chr. Bronchiolitis (Air-Trapping)

- In smokers, air trapping is correlated with inflammatory infiltration of the smooth muscle layers of small layers.
  Berger P. Radiology 2003
- Most important site of airflow obstruction
  Hogg JC, N Eng J Med 2004

Component 3: Chr. Bronchitis

- Bronchial wall thickening
- Luminal Narrowing
- Moderate bronchiectasis in lower lobes

Remy-Jardin M, Radiology 1993

CT of COPD: From Morphology to Function

1. Detection of disease (& disease components)
   - Emphysema / Bronchiolitis / Bronchitis
2. Quantification of disease components:
   indirect assessment of lung function
   - Quantification of emphysema, airway wall changes: Correlation with PFT
   - Standardization of image acquisition and analysis
3. Future: direct visualization of function
   - Ventilation, air-trapping, perfusion

Emphysema Quantification: Density Histogram

Normal Lung

Emphysema

Quantification Metrics

- LAA (Low-Attenuation Area) or EI (Emphysema Index)
- Volume fraction of lung below threshold (<-950HU)
- Mean lung density
- Percentile index (ex. 15%)

CT Quantification vs. Clinical Parameters

- Inverse correlation between CT emphysema index and PFT parameters (FEV1, FVC, FEV1/FVC, DLCO)
  Sanders C et al. Invest Radiol 1988
  Kinsella M et al. Chest 1990
- in moderate to severe emphysema
- poor correlation in mild diseases
- Other clinical parameters
  - osteoporosis (Ohara T, Chest 2008)
  - exercise capacity, BODE index (Lee YK, Lung 2008)
  - respiratory symptoms (Grydeland TB, 2010, AJRCCM)
**CT Emphysema Quantification: Clinical Values**

- Useful in selecting patients in LVRS (Martinez FJ, Am J Respir Crit Care Med 2006)
- Sensitive to monitor disease progression (Stolk J, Respir Med 2007)
- Associated with COPD exacerbations (Han MK, Radiology 2011)
- Emphysema extent can predict mortality (Haruna A, Chest 2010)

**Objective Measurement of Airway**

- **Full-width Half-maximum Method**

\[
\text{Wall area} \% = \frac{\text{Wall area (WA)}}{\text{Wall area (WA)} + \text{Lumen area (LA)}} \times 100
\]

**Large Airway in COPD**

- Thicker airway wall in smokers with COPD than smokers or nonsmokers without COPD.
- Airway walls of pts who have COPD with chronic bronchitis are thicker than those who have COPD without chronic bronchitis.
  Orlandi I et al. Radiology 2005
- Distal (small) airways rather than proximal (large) airways are the more important determinant of airflow limitation in COPD.

**Technical Consideration in Emphysema Quantification**

- Radiation exposure
- Reconstruction kernel
- Reconstruction thickness
- Respiration
- Software parameters: threshold for lung extraction, emphysema

**Standardization is important !!**

<table>
<thead>
<tr>
<th>Factors</th>
<th>Condition</th>
<th>Emphysema Quantification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation exposure</td>
<td>( m \text{As} )</td>
<td>↑</td>
</tr>
<tr>
<td>Reconstruction kernel</td>
<td>High-frequency</td>
<td>↑</td>
</tr>
<tr>
<td>Slice thickness</td>
<td>Thinner</td>
<td>↑</td>
</tr>
<tr>
<td>Respiration status</td>
<td></td>
<td>Variable</td>
</tr>
<tr>
<td>Lung/emphysema threshold</td>
<td></td>
<td>Variable</td>
</tr>
</tbody>
</table>

- For longitudinal studies, all of the followings should be same:
  - CT scanner, CT protocol (exposure condition, thickness, kernel, etc), respiratory instruction, and software

**Airway Measurement: Current Status**

- Various method: different result
  - manual or semi-automatic border tracing
  - full-width-half-maximum (FWHM) method
  - Maximum likelyhood method
  - Watershed segmentation
  - Integral based methods
- Lack of standardization
- Same software should be used for follow-up study
- Airway wall thickness/area tends to be overestimated if the wall thickness was 1 mm or less.
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   - Perfusion, ventilation, air trapping

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**One-Stop Severity Assessment of Emphysema by Using DECT**

- Perfect registration between high-resolution CT and perfusion map
- Additional radiation dose (-)

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**Combined Perfusion / Parenchymal Destruction Assessment in Emphysema with DECT Energy CT**

- 27 patients with emphysema
- Significant correlation btw.
  - VNC: EI vs. PFT
  - perfusion index vs. EI
- Virtual noncontrast image and iodine maps from DECT provide combined regional / global quantitative information on parenchymal destruction and perfusion in emphysema

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**Xenon Ventilation CT**

- Contrast material: Xenon Gas
  - Similar Atomic Number (54) to Iodine (53)
  - CT Density of Airspace Containing Xe Increases Linearly with Xe Concentration
- Pilot study with 30% Xenon

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**Normal vs. COPD**

- Xenon ventilation CT using Dual-energy CT is a feasible tool for assessment of ventilation,
  - Without significant side effects at concentration of 30%
  - Providing accurate measurement of Xe enhancement without influence of different lung volume
- Wash-in and wash-out xenon ventilation CT is feasible.

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**Quantification of Air Trapping**

- Using exp. CT alone: Challenging, because it should be separated from air remaining in emphysema
- By comparing ins/exp CT
  - Possible to visualize local difference in ventilation
- Problem: Non-uniform lung expansion during ventilation
Quantification of Air Trapping in COPD: Automatic Registration of insp./exp. CT scans

- Optical flow method to assess regional air trapping
  Torigian DA, Getter WB, AJR 2007

CT Assessment of COPD: Perspective

- Morphology + Function (Ventilation + Perfusion)

Take Home Messages

1. Reliable CT quantification of emphysema and airway wall changes in COPD is possible.
2. Understanding technical factors influencing the quantification such as, radiation dose, reconstruction kernel, slice thickness, respiration status and software parameter is critically important.
3. With new CT techniques, simultaneous morphologic and functional assessment of COPD will be possible.

References