

# Quantitative Lung CT: Reference and Consistency Standards

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## Quantitative Lung CT

Quantitative lung CT measures physical characteristics of the lung and facilitates regional analysis of those quantities. CT attenuation measurements of lung density and lung volume are surrogate measures for severity of emphysema, degree of air trapping, and degree of hyperinflation in COPD and asthma. Airway lumen area and airway wall thickness measurements are surrogates for severity of inflammation of the airways.

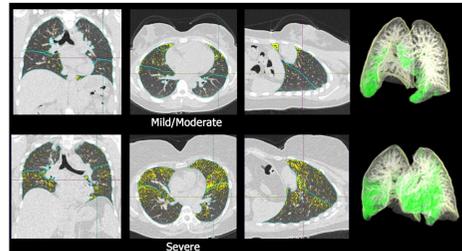
### Emphysema

The extent of emphysema is estimated using the density mask technique, where the percent emphysema is the percentage of lung voxels at total lung capacity with CT attenuation below a given threshold.

- The standard threshold used for the severity of emphysema is -950 HU.
- The nth percentile method is defined as the threshold at which n percent of all voxels have a lower density. 15th percentile is preferred.
- Both methods are biased by the pixel noise.
- Both are sensitive to reconstruction kernel, radiation dose, and slice thickness.
- Median lung CT number is preferred.
- Not biased by noise and can be supported with phantom measurements.

### Air Trapping

Air trapping is obtained at functional residual capacity and the threshold for the mask is -856 (Figure below).



Regional distribution of air trapping shown in green for mild/moderate (top row) and severe (bottom row) asthma subject. From the Severe Asthma Research Program (SARP)\*\*\*.

### Airway morphology

Airway morphology includes the airway lumen areas and airway wall thicknesses. More distal airways (3<sup>rd</sup> to 6<sup>th</sup> airway generations) correlate with pulmonary lung function measures.

#### If you are interested in more information

Quantitative CT Imaging of the Lung  
Hyatt Regency Huntington Beach  
Huntington Beach, California

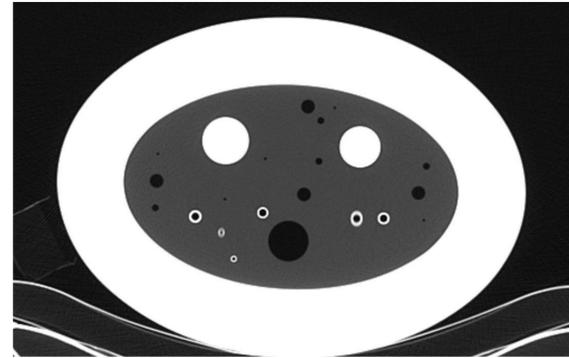
This one day course, co-sponsored by the Society of Thoracic Radiology and the Quantitative Imaging Biomarkers Alliance, will summarize the current state of knowledge regarding the role of quantitative CT of the lungs in diffuse lung disease. Scheduled the day before the STR Annual Meeting

On-line Registration for course:

<http://www.thoracicrad.org/meetings/index.htm>

## COPDGene\*\* Reference Test Objects

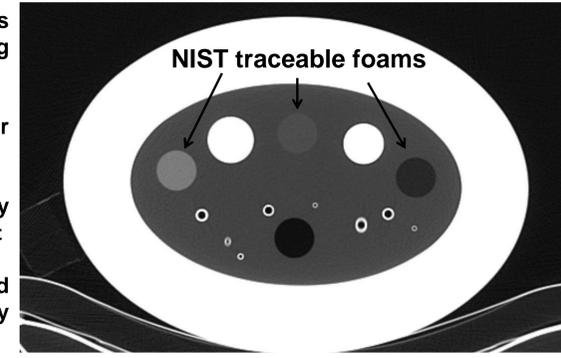
### Original Model



### Previous Observations

- Consequences of CT shifts on measures of emphysema and degree of air trapping is under investigation.
- No systematic difference in water or acrylic CT numbers was observed.
- Results suggest that single foam density in the Reference Test Object is insufficient
- Multiple foam density standards needed for quantitative lung CT density calibration.

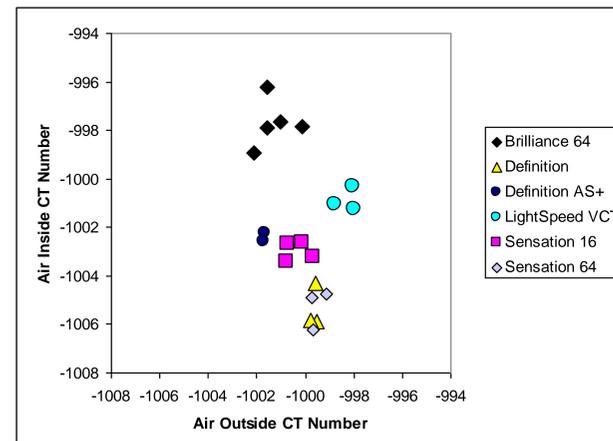
### Modified Model



### COPDGene Study experience with test object

The COPDGene Reference Test objects are objects containing foams with CT numbers approximating those in lung.

- The Test Objects consist of an outer ring and insert.
- The size and shape of a COPDGene Reference Test object is similar to that of the adult human chest, resulting in equivalent effects of beam hardening, x-ray scatter and dose to the adult human.
  - The outer ring (35cm by 25cm with thickness of 5cm, CT number 15HU at 120kV) is unchanged in the two versions of the Test Object.
  - The insert is a foam cylinder with a CT number of -850HU to -860HU.
  - Details are implanted in the foam. The large (3cm in diameter) sized objects include an acrylic rod, a tube containing water, and an air hole.
  - The 6 polycarbonate tubes were used to simulate airways in the original design. Two smaller tubes were added to simulate smaller airways.
  - The small air holes were removed in the new design as they were not used.
- The original Test Object design was used for quality assurance at the 20 sites of COPDGene Study.
- The Test Objects were scanned monthly using all 44 CT scanners included in the COPDGene Study.



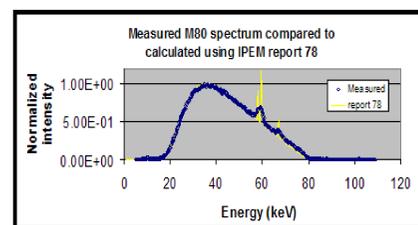
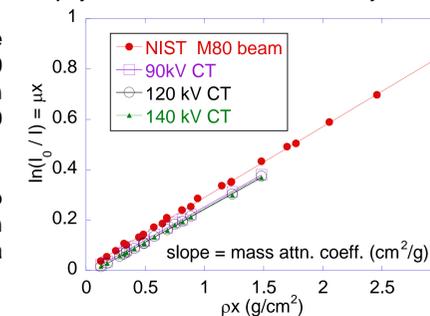
Changes in CT number for foam and air were observed in 5 scanners due to new calibration or software upgrades. The CT number of air within the phantom also differed among scanners.

### NIST traceable lung CT reference standard

National Institute of Standards and Technology (NIST) of the US Department of Commerce is charged with developing measurement standards for US industries.

- Participation in the QIBA COPD/Asthma Technical Committee
  - Identifying and characterizing the foam samples as a candidate for a standard reference imbedded in the insert of improved design.
  - The class of foams previously studied in various CT machines.
  - Nominal HU value per unit density is (950 +/- 10) HU/(g/cm<sup>3</sup>).
- Recent effort in a lung density reference material for CT measurements
  - Transmission measurement performed at the NIST standard x-ray beam (M80) using a solid state x-ray camera.
  - commercial foam with five densities (from 0.06 to 0.30 g/cm<sup>3</sup>) with the attenuation thickness ranges from 1.9 cm to 10 cm.
  - Transmission measurements were also performed in a CT beam using the Surview mode in a Philips\* scanner at NIST.

Foam blocks (1.9 cm x 2.7 cm x 5.0 cm) oriented and stacked to vary the attenuation thickness.  
Effective mass attenuation coefficient of polyurethane foam blocks in various x-ray beams



	slope (cm <sup>2</sup> /g)	std
M80	0.281	0.011
90 kV CT	0.263	0.0035
120 kV CT	0.263	0.0033
140 kV CT	0.260	0.011

Calculated effective mass attenuation for polyurethane using the measured M80 spectrum: 0.284 cm<sup>2</sup>/g.

- Effort is underway to associate the measured effective attenuation with the HU, and to investigate a spectral independent description of the material's HU value using the dual-energy method.

\*Any mention of commercial products is for information only; it does not imply recommendation or endorsement by NIST.

## Quantitative CT for Airway Morphology Assessment

The wall thickness and the lumen radius of the 6 tubes using 0.75mm slice images of the original model of the Test Object were measured using the FWHM method. These measurements accounted for the tube's orientations and were evaluated over regions that spanned 30 mm. The measurements did not account for the finite resolution.

Tube	Wall Thickness	Luminal Diameter	Orientation
1	0.6	1.5	45 degree
2	0.6	1.5	Axial
3	0.9	3	Axial
4	1.2	3	45 degree
5	1.2	3	Axial
6	1.5	3	Axial

Units are mm

Wall Thickness      Luminal Diameter

Tube	Average	Standard deviation	Coefficient of variation	Average	Standard deviation	Coefficient of variation
1	1.459	0.068	4.7%	1.010	0.042	4.1%
2	1.520	0.076	5.0%	0.972	0.049	5.0%
3	1.548	0.083	5.3%	2.609	0.049	1.9%
4	1.671	0.052	3.1%	2.708	0.038	1.4%
5	1.715	0.069	4.0%	2.665	0.042	1.6%
6	1.857	0.065	3.5%	2.758	0.041	1.5%

## Next steps for the COPD/Asthma Technical Committee

- Determine the consequence of CT scanner inconsistencies identified on COPDGene Study scanners on the severity of emphysema, degree of air trapping metrics of COPDGene cases in order to develop methods to obtain consistent measurements.
- Use the COPDGene Reference Test object to determine the causes of CT scanner inconsistencies.
- Work with manufacturers to standardize CT attenuation measurements at lower end of the Hounsfield scale using COPDGene Reference Test Object by developing a QIBA COPD/Asthma Profile.
- Review in vivo repeatability and establish repeatability claim. Recommend a volume correction that will enhance in vivo repeatability and assess magnitude of improvement.
- Develop a better understanding of what is considered normal on QCT for both inspiratory and expiratory scans. Continue this discussion at Quantitative CT Imaging of the Lung Course, co-sponsored by the Society of Thoracic Radiology and the Quantitative Imaging Biomarkers Alliance.

\*\* The Genetic Epidemiology of COPD Study ([www.COPDGene.org](http://www.COPDGene.org)) is a study to identify genes that increase an individual's risk of developing COPD. The Study evaluated 10,000 subjects using 44 CT scanners.

\*\*\* The SARP Study (<http://www.severeasthma.org/>) studies asthma severity and progression and also uses the COPDGene Reference Test.