Quantitative CT of Obstructive Lung Disease: Towards More Robust and Accurate Measurements

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Quantitative Lung CT Measures
Quantitative CT measures in obstructive lung disease emphasize measures of low density lung parenchyma and central airway structures. These measures, especially their regional extent and distribution, are potential surrogates for quantitative measurements of emphysema, air trapping, and airway remodeling in chronic obstructive pulmonary disease (COPD) and asthma.

Density Threshold Measures
One of the more established measures is the "low attenuation area" or "emphysema index" defined as the percentage of lung voxels at total lung capacity (TCL) with CT attenuation below a given threshold. These threshold standards used for severity of emphysema include -950 Hounsfield units (HU) and -910 HU. The -950 HU threshold has been validated with histology, while the -910 HU threshold is thought to be less sensitive to image noise for detecting mild to moderate disease.

Air trapping is also evaluated using a density threshold, but the CT exam is obtained at a lung inflation volume corresponding to functional residual capacity (FRC) and the threshold for the mask is -850 HU. The rationale for this choice is based on empirical measures of air vs. tissue density that have been translated to quantitative studies in asthma (Figure 1).

Density Threshold for Air Trapping in Asthma (-850 HU at FRC)

Cumulative Histogram of Attenuation Values for Expiratory Lung (-850 HU at FRC)

Density Correction Using Improved Test Object Design
The current design of the COPDGene Reference Test Object contains 5 10 cm long tubes with numbers similar to lung CT numbers (Figure 3). The Test Object consists of an outer ring and insert. The size and shape is similar to the airway human chest. So it will have beam hardening, x-ray scatter and dose equal to the adult human lung.

Reducing the display color of view with a higher resolution modulation transfer function (MTF) improves accuracy of wall thickness (Figure X) and lumen measures. Adoptive statistical iterative reconstruction (ASIR) yields comparable results.

NIST SRM 2088: Lung CT reference standard

• Development of lung density reference standard (SRM 2088)
• 5-density foam suite corresponding to the range of lung densities calibrated with SI traceable density certification

Density of the 200 foam blocks as a function of the HU values measured in a medical CT machine (purple circle, left vertical axis); and the residuals from the mean lot density (red square, right vertical axis).

NIST standard reference foams vs the reference foams inserted in the COPDGene phantom

Next steps for the COPD/Asthma Technical Committee
• Develop methods to obtain consistent CT measurements across CT platforms of the severity of emphysema, degree of air trapping metrics of COPD cases.
• Improve the accuracy of quantitative CT while reducing radiation dose.

Technical Committee is committed to developing a lower-dose emphysema reference method and profile – less than 50mAs.

Committee is evaluating the utility of current modulation protocols and statistical reconstructions.

• Work with manufacturers to standardize CT attenuation measurements at lower end of the Hounsfield scale using the COPDGene Test Object.

The COPDGene Test object was scanned at 6.65 mCi CT dose. The wall thickness and lumen diameter of the 6 axially oriented tubes using 0.5 mm slice images of the Test Object (labeled 1-6 in Fig. 3) were measured over 30 mm axial ranges using the FWHM method. The significant over-estimation of wall thickness and underestimation of smaller airway lumen diameters (2, 4, and 6) suggests spatial resolution is limiting (Table 2).

Quantitative CT for Airway Morphology Assessment
Airway morphology is the measurement of the airway lumen areas and airway wall thicknesses. Typically more distal airways (3rd to 6th airway generations) correlate better with pulmonary lung function measures suggesting that distal segments are most relevant for depicting regional disease.

Table 2: Quantitative analysis of wall and internal/external lumen areas (1a is in Figure 4)a

Using the COPDGene test object, calibration across sites or time (e.g. during longitudinal studies) becomes feasible. The consequences of shifts in CT number on the severity of emphysema and degree of air trapping metrics is under investigation. However, one potential approach is to use attenuation of air in the trachea to linearly correct the scale of measurements (Figure 4).

Figure 6: Improved calibration with whole lung function (HLF-FHC) measures better up and after (A) correcting for differences in density within the trachea.