Volumetric Expiratory HRCT of the Lung: Clinical Applications

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KEYWORDS

- Computed tomography (CT) • Lung • High-resolution CT
- Expiratory high-resolution CT • Volumetric

Expiratory high-resolution CT scan (HRCT) of the chest offers a powerful adjunct to inspiratory HRCT in the detection of lung diseases involving the small airways by reflecting the interplay of air in the alveoli, the pulmonary interstitium, and pulmonary blood volume.[1–5] The hallmark of expiratory airflow obstruction has been the radiographic finding of air trapping where lung regions with a lesser degree of increase in expiratory attenuation than normal are thought to be indicative of retained gas in the secondary pulmonary lobule.[1,3] This process can be found in a variety of lung diseases with obstructive physiology, including asthma, bronchiectasis, and emphysema.

A major limitation to acquiring expiratory CT scans on all patients is the associated radiation exposure. Because of this, in 2003, two of the authors (Nishino and Hatabu) and their colleagues[6,7] developed a clinical volumetric expiratory HRCT protocol with the decreased tube current that provides volumetric data sets of the entire thorax at end-inspiration and at end-expiration without increasing radiation dose and examination time. These volumetric data sets of expiratory HRCT images allow for full visualization of the airway and lung parenchyma, with the added value of the three-dimensional and multiplanar capability (**Fig. 1**).[6,7] Volumetric expiratory HRCT has since been used for evaluation of diffuse lung disease with suspected airway abnormalities. More recently, the Chronic Obstructive Pulmonary Disease Gene (COPDGene) Study, a multicenter investigation of the genetic epidemiology of subjects with chronic obstructive pulmonary disease (COPD) supported by National Institute of Health, adopted volumetric inspiratory and expiratory HRCT for its protocol.

COPD

COPD is defined as incompletely reversible expiratory airflow obstruction.[8] It is typically related to tobacco smoke exposure and is the result of remodeling of the small airways with obliteration of their lumen and loss of lung elastic recoil due to emphysematous destruction of the parenchyma.[9] Standard objective measures of both of these processes, airway disease and emphysema have been well established using inspiratory CT scanning.[10] Less well recognized are the potential contributions that expiratory CT scanning can be made to further understanding of these processes

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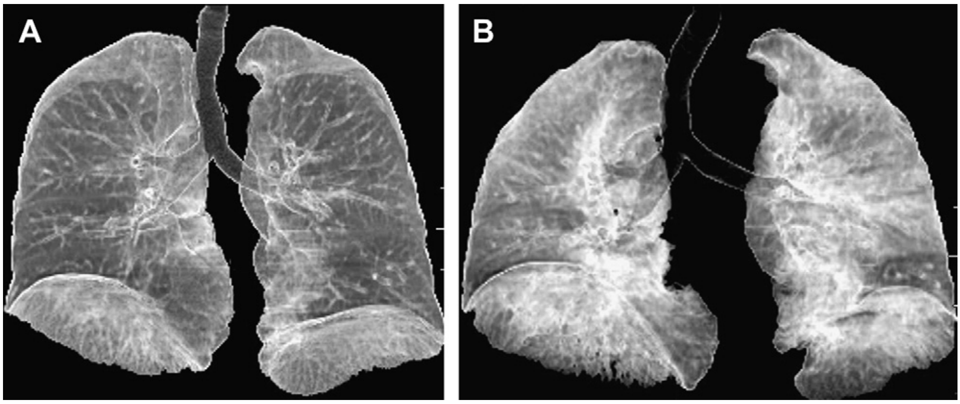

Fig. 1. A 70-year-old woman with a history of bronchial asthma. (*A*, *B*) The reconstructed images with volume rendering of the posterior two-thirds of the lungs at end-inspiration and end-expiration using an ADW workstation. Volume and attenuation changes after expiration are visually displayed in a 3-dimensional fashion, providing easy recognition of air trapping. There are marked changes in the configuration of the airway conducting to the areas of air trapping. (*From* Nishino M, Boiselle PM, Copeland JF, et al. Value of volumetric data acquisition in expiratory high-resolution CT of the lung. J Comput Assist Tomogr 2004;28:209–14; with permission.) ADW, Advanced Development Workstation.

using quantitative measures of gas trapping and CT attenuation gravitational gradients.

Densitometric assessments of the lung parenchyma have been accepted methods for quantitatively examining CT scan burdens of emphysema since the 1980s.[10] These methods have been benchmarked against histopathologic examination and have been integral to most CT scan-based epidemiologic studies of subjects with COPD.[10–13] With the advent of volumetric expiratory CT scan imaging protocols came the recognition that similar densitometric methods can be applied to these images. Recently, Akira and colleagues[14] found that such objective analysis of the expiratory images of subjects with COPD may offer stronger correlates to lung function than inspiratory scans in subjects with severe disease. Additional studies in larger cohorts will likely support such observations and further argue for the phenotypic information available in expiratory CT scans.

It has been known that CT demonstrates an attenuation gradient in the normal lung, with the greatest density in dependent lung regions and the least density in nondependent lung regions. In 1993, Webb and colleagues[2] reported that the anteroposterior attenuation gradient is discontinuous at the major fissure, and that the posterior aspect of the upper lobe has greater attenuation than the anterior aspect of the lower lobe. It was also noted that the anteroposterior intralobar attenuation gradient was accentuated during expiration. Departure from these gradients could imply local abnormalities in lung compliance, distribution of mechanical stress, or distensibility of vessels.[2,15] However, the significance of the loss of this intralobar attenuation gradient has not been determined in detail.

The authors investigated 21 consecutive patients with emphysema studied with volumetric expiratory HRCT, and 6 patients with normal HRCT. The anterior-posterior intralobar attenuation gradients were quantified on end-inspiratory and end-expiratory sagittal reformations using a lung analysis software program.[16] The quantitative values of the intralobar attenuation gradients were correlated with pulmonary function test results (**Figs. 2** and **3**). The intralobar attenuation gradients in the patients with forced expiratory volume in 1 second (FEV_1), by percent, of less than 70% were significantly smaller compared with those in patients with FEV_1(%) greater than 70% in right lower lobe at end-inspiration, and right and left lower lobes at end-expiration. There was a significant positive correlation between the intralobar attenuation gradient and pulmonary function test results in bilateral lower lobes, when the cutoff values of 70% for FEV_1(%) and 0.002 for attenuation gradient were used. The intralobar attenuation gradients in bilateral lower lobes at end-expiration were significantly correlated with FEV_1 and FEV_1 per forced vital capacity (FVC). These results indicated that the quantitatively measured intralobar attenuation gradients correlate with obstructive changes on pulmonary function tests in patients with emphysema, especially at end-expiration in the lower lobes, suggesting a potential utility of