Dynamic Oxygen-Enhanced MR Imaging vs. Quantitative CT: Efficacy of Pulmonary Functional Loss Assessment and Clinical Stage Classification of Smoking-Related COPD

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Introduction: Cigarette smoking is the most important risk factor of chronic obstructive pulmonary disease (COPD). Several investigators try to evaluate the functional loss due to cigarette smoke by CT, although CT can only demonstrate the regional structural change. Oxygen-enhanced MR imaging offers an alternative approach for assessment of regional pulmonary function (1, 2). In addition, some investigators suggested the possibility of dynamic oxygen-enhanced MR imaging for assessment of wash-in time of oxygen by respiration (3-5). However, no direct comparison has been published in the literature of the efficacy of quantitatively assessed CT and oxygen-enhanced MR imaging for smoking-related functional loss assessment and clinical stage classification of smoking-related COPD subjects.

We hypothesized that dynamic oxygen-enhanced MR imaging might make it possible to assess not only alveolocapillary gas transfer but also airway obstruction in smoking-related COPD patients, and might be more effective for assessment of regional functional loss and clinical stage, when compared with quantitative CT based on density-masked CT technique. The purpose of the study reported here was to directly compare the efficacy of dynamic oxygen-enhanced MR imaging and quantitative CT for smoking-related pulmonary functional loss assessment and clinical stage classification of smoking-related COPD.

Method and Materials: Six non-smoking (five men and one woman; age range 27 to 46 years; mean age 38 years) and 51 consecutive smoking-related COPD subjects (38 men and 13 women; age range 36 to 76 years; mean age 56 years) underwent dynamic oxygen-enhanced MR imaging, CT and pulmonary function tests. COPD subjects were classified into five clinical stages based on the American Thoracic Society-European Respiratory Society (ATS-ERS) guidelines. All oxygen-enhanced MR imaging were performed with a centrically-reordered inversion recovery single shot turbo spin echo sequence (TE 4 ms/ TI 900 ms/ echo spacing 4 ms, 3 slices) using a 1.5T whole body scanner (Gyroscan Intera, Philips Medical Systems, Best, The Netherlands).

From signal intensity-time course curve of dynamic oxygen-enhanced MR data in each subject, regional relative enhancement ratio and wash-in time of molecular oxygen maps were generated by pixel by pixel analyses. Then, mean relative-enhancement ratio and mean wash-in time in each subject was determined as the average of regional oxygen-enhancements and wash-in times in 6 spatially defined regions of interest (ROIs) in both lungs on three coronal planes (total 18 ROIs). From density-masked CT, degree of smoking-related pulmonary emphysema in each subject was calculated functional lung volume by using a commercially available soft ware.

For the comparison of efficacy of assessment of smoking-related functional loss, the three parameters were correlated with forced expiratory volume in 1 second (FEV_1%) and diffusing capacity of the lung (DL_{CO}/V_A). To determine the efficacy of clinical stage classification, these parameters were statistically compared for non-smoking subjects and all clinical stages of smoking-related COPD subjects by using Tukey's HSD test. A p value less than 0.05 was considered as significant in each statistical analysis

Results: All dynamic oxygen-enhanced MR imaging examinations were completed successfully. No adverse effects were observed. Representative cases are shown in Figure 1 and 2. Correlation between mean wash-in time and FEV_1% ($r=0.80$, $r^2=0.69$, $p<0.0001$) and between mean relative-enhancement ratio and DL_{CO}/V_A ($r=0.78$, $r^2=0.61$, $p<0.0001$) was stronger than that between functional lung volume and either FEV_1% ($r=0.72$, $r^2=0.52$, $p<0.0001$) or DL_{CO}/V_A ($r=0.67$, $r^2=0.45$, $p<0.0001$). Statistical results for mean wash-in time, mean relative enhancement ratio and functional volume for non-smoking subjects and smoking subjects at all stages are shown in Table 1. Mean wash-in time showed a significant difference among non-smoking and all clinical stages of smoking-related COPD subjects ($p<0.05$), although mean relative-enhancement ratio and functional lung volume showed a significant difference among non-smoking subjects and all clinical stages except "At risk of COPD" and "Mild COPD" subjects.

Conclusion: Dynamic oxygen-enhanced MR imaging is potentially more effective than quantitative CT for assessment of smoking-related pulmonary functional loss and clinical stage classification of smoking-related COPD patients.

Fig. 1a Fig. 1b Fig. 1c

Figure 1. 38-year-old non-smoking volunteer.
a: Routine CT demonstrates no low attenuation area in both lungs. On quantitative CT, homogeneously functional lung is shown in red, pulmonary emphysema in gray, and fibrosis in white. b: Wash-in time map demonstrates homogeneous and relatively short regional wash-in time in both lungs. Mean wash-in time was 16.0 sec. c: Relative enhancement map shows homogenous and relatively high relative-enhancement ratio in both lungs. Mean relative-enhancement ratio was 0.20.

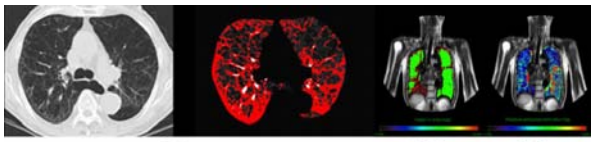

Fig. 2a Fig. 2b Fig. 2c

Figure 2. 76-year-old smoking subject with Brinkman's index of 1480.
a: Routine CT demonstrates multiple low attenuation areas due to pulmonary emphysema in both lungs. On quantitative CT, heterogeneously functional lung is shown in red, and pulmonary emphysema in gray. b: Wash-in time map demonstrates heterogenous and markedly prolonged regional wash-in time in both lungs. Mean wash-in time was 53.0 sec. c: Relative-enhancement map shows heterogeneously and markedly reduced relative-enhancement ratio in the both lungs. Mean relative-enhancement ratio was 0.08.

Table 1. Statistical results for mean wash-in time, mean relative-enhancement ratio and functional volume for non-smoking subjects and smoking subjects at all stages.

		Non-smoking subjects	Smoking subjects				
			ATS-ERS classification				
			At risk for COPD	Mild COPD	Moderate COPD	Severe COPD	Very severe COPD
Mean wash-in time (sec)	(mean±SD)	19.8±3.5	26.2±6.4*	30.0±7.3*	38.0±8.7*, **, ***	55.1±6.2*, **, ***, ****	55.5±3.5*, **, ***, ****
Mean relative-enhancement ratio	(mean±SD)	0.19±0.07	0.18±0.08	0.16±0.06	0.11±0.04*, **, ***	0.07±0.02*, **, ***	0.07±0.01*, **, ***
Functional lung volume (%)	(mean±SD)	73.8±13.0	74.0±12.7	68.3±13.5	49.9±15.1*, **, ***	43.4±11.9*, **, ***	30.5±9.9*, **, ***

*: Significant difference with non-smoking subjects ($p<0.05$).
**: Significant difference with smoking subjects assessed as "At risk of COPD" ($p<0.05$).
***: Significant difference with smoking subjects assessed as "Mild COPD" ($p<0.05$).
****: Significant difference with smoking subjects assessed as "Moderate COPD" ($p<0.05$).

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