Second-Order Texture Analysis of Hyperpolarized ^{3}He MRI - Beyond the Ventilation Defect

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Audience: Scientists and clinicians interested in pulmonary functional magnetic resonance imaging (MRI) to evaluate lung disease.

Purpose: Hyperpolarized ^{3}He magnetic resonance imaging (MRI) provides high-resolution images of pulmonary ventilation. Current image processing methods for evaluating pulmonary ventilation heterogeneity focus on quantifying ventilation and ventilation defects[1] but these metrics do not fully exploit the rich content in MR ventilation images. Ventilation texture may also provide physiologically-relevant information and we have observed that patients with similar ventilation defect percent (VDP) can have different local and regional ventilation patterns as depicted on MRI, suggesting that there are measureable differences in ventilation heterogeneity that are not reflected by VDP. Based on these observations, we hypothesized that a second-order texture measurement of ^{3}He MRI ventilation images would provide a way to quantify and characterize ^{3}He ventilation heterogeneity.

Methods

Subjects: Participants provided written informed consent to an approved study protocol including: elderly never-smokers (< 1 pack year) with no history of previous chronic or current respiratory disease, ex-smokers (≥10 pack years) without airflow limitation and subjects with asthma.

Image Acquisition: MRI was performed on a whole body 3.0 Tesla Discovery MR750 (GE Health Care, Milwaukee, WI) with broadband imaging capability as previously described.[1] ^{1}H MRI was acquired with a fast spoiled gradient-echo (16s total data acquisition, relaxation time (TR)/echo time (TE)/flip angle = 4.7 ms/1.2 ms/30°, field-of-view (FOV) = 40×40 cm, matrix 128×128, 14 slices, 15 mm slice thickness, 0 cm gap) during a 1L inspiratory breath-hold of medical grade N_2. For ^{3}He MRI, ventilation images were acquired using a two-dimensional gradient echo sequence (14s data acquisition, TR/TE/flip angle = 4.3 ms/1.4 ms/7°, FOV = 40 × 40 cm, matrix 128×128, 14 slices, 15 mm slice thickness, 0 gap) during inspiratory breath-hold of a 1L ^{3}He/N_2 (5ml/^{3}He body weight diluted to 1L with N_2) mixture.

Texture Analysis Algorithm: To generate second-order texture features, statistical analyses of a gray-level co-occurrence matrix (GLCM)[2] were performed. As shown in Figure 1, we developed a semi-automated algorithm consisting of five steps. In the first step, the MR image was altered with a 10×10 median filter, the purpose of which was to smooth surrounding image noise and maintain the ^{3}He ventilation signal boundary. Step 2 applied a maximum entropy filter to the filtered image (B) and returned a binary mask showing ventilated regions with a value of 1 and all other regions with a value of 0 (C). Step 3 involved the multiplication of the entropy mask (C) by the original raw data image (A). This resulted in an image matrix showing only ^{3}He ventilation surrounded by zero-valued pixels (D). In step 4 the trachea was removed from the ventilation mask to yield (E) – the final ventilation mask. A GLCM was generated from (E), step 5. Special consideration was given to the exclusion of zero-valued pixels in the GLCM in step 5. The ^{3}He ventilation signal in (E) is surrounded by zero-values, and if these zero – zero pixel pairs were included in the GLCM a large peak would appear at $(i, j) = (0, 0)$ in the GLCM. This would result in the inclusion of a large homogeneous area into the texture measures. Since only texture features from the ventilation signal were required, the GLCM was modified to exclude zero–zero pixel pairs and pixels adjacent to zero-valued pixels (such as at boundaries between signal and no signal). When generating a GLCM, the directional orientation was taken into account because a GLCM estimated in only one direction (*ie.* evaluating pixel pairs in only one direction) would result in directional bias. Therefore neighboring pixels were evaluated in four directions in the coronal plane: $(i,j) = (-1,0), (-1,-1), (0,1)$ and $(1,-1)$. In this way, GLCMs were generated for each direction and texture features from each GLCM were averaged. Texture measurements were generated for each slice of the MRI volume and the whole-lung texture was generated as the mean across all slices. Five different second-order texture features were generated[3]: ***inertia (contrast)*** – the variation in gray-level intensity between neighboring pixels, ***homogeneity (inverse different moment)*** – the consistency of gray-level intensity between adjacent pixels, ***entropy*** – the complexity of gray-level intensities in an image, ***correlation*** - the correlation of gray-level intensities between pixel pairs and ***energy*** – the textural uniformity in the image. These five texture features were used because together they provide an understanding of signal intensity patterns throughout the region-of interest.

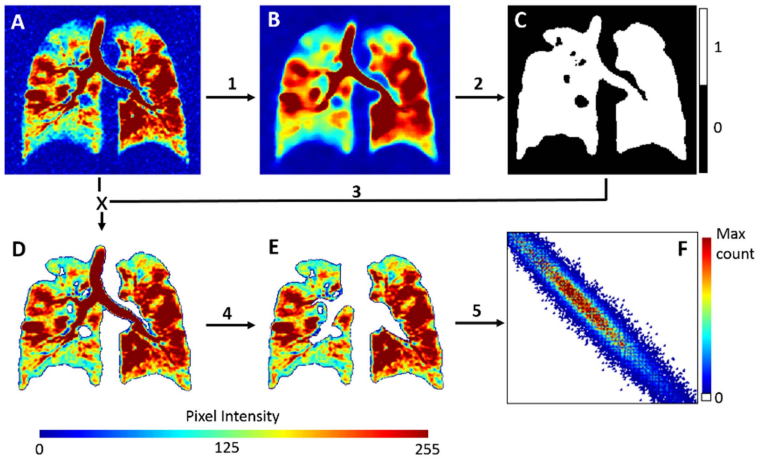

Figure 1: Texture Analysis Pipeline. A) raw ^{3}He MRI shown in colour to highlight signal intensity differences. **B**) filtered MR image used to generate **C,** the maximum entropy mask. **C)** is multiplied by the raw MR image to extract the ^{3}He ventilation mask **D**. **E)** ^{3}He ventilation mask with trachea and main bronchi removed. **F**) gray-level co-occurrence matrix (GLCM) generated from the ventilation mask. Second-order texture features are generated from GLCM in **F**.

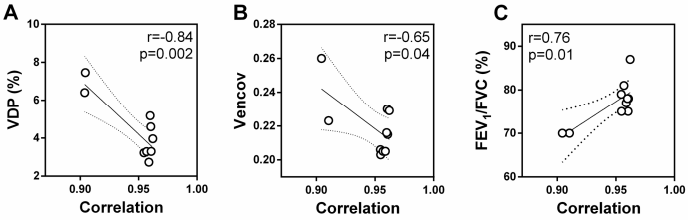

Figure 2: Significant relationships in never-smokers. In never-smokers, *correlation* was significantly related with **A)** ^{3}He VDP (r=-0.8, p=0.002) **B)** ^{3}He ventilation coefficient of variation (Vencov) (r=-0.6, p=0.04) and **C)** ratio of forced expiratory volume 1s to forced vital capacity (FEV_1/FVC) (r=0.8,

Results: Preliminary results were generated using a test dataset of n=30 subjects consisting of 10 elderly never-smokers, 10 ex-smokers without airflow limitation and 10 asthmatics. As shown in Figure 2, in never-smokers, the texture measurement of *correlation* was significantly correlated with ^{3}He ventilation defect percent (VDP) (r=-0.84, p=0.002) and ^{3}He ventilation coefficient of variation (Vencov) (r=-0.65, p=0.04) and with the spirometry measurement of the ratio of the forced expiratory volume in 1s to forced vital capacity (FEV_1/FVC) (r=0.76, p=0.01). As expected for second-order texture analyses, *homogeneity* was significantly correlated with *inertia* and *energy* when data for all subjects was evaluated.[2]

Discussion and Conclusions: We generated a second-order texture analysis algorithm to provide ventilation heterogeneity information derived from ^{3}He MR ventilation imaging. Preliminary results in a test dataset showed that ^{3}He MRI texture measurements in healthy subjects correlated with VDP, Vencov and spirometry (FEV_1/FVC). Future work will be focused on applying the algorithm to a larger dataset of subjects with and without pulmonary disease to uncover clinically-relevant texture information in ^{3}He MRI.

References: 1. Kirby, M. *et al. Acad Radiol* (2012) 2. Haralick, R. M. *et al., IEEE Sys Man Cyber* (1973) 3. Conners, R. W. *et al., IEEE TPAMI* (1980)