Non-contrast-enhanced free-breathing lung imaging using high-speed MRI data acquisition and phase dispersion analysis

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Target Audience: Researchers in the field of lung imaging and magnetic susceptibility imaging.

Purpose: To develop a non-contrast-enhanced lung imaging technique based on high-speed dynamic data acquisition and phase dispersion analysis.

Introduction: This work aims to develop a novel non-contrast-enhanced lung MRI technique that can image function of the lung dynamically during free breathing. The presented technique uses high-speed dynamic data acquisition and generates image contrast in pulmonary parenchyma from dynamic changes of MRI phase dispersion caused by respiration. In contrast to other non-contrast-enhanced techniques[1,2], this technique uses dynamic data acquisition with a higher imaging speed for reduced motion artifacts and does not require image registration algorithms. In addition, MRI phase dispersion may provide dynamic information about regional susceptibility changes in the lung during respiration.

Methods: The presented technique evaluates MRI phase dispersion in dynamic lung images and uses those dynamic changes to generate image contrast in the lung. To avoid motion artifacts during inspiration and expiration, ~ 10 dynamic lung images are collected per second.

A) High-speed dynamic data acquisition: To achieve a sufficiently high speed, each image was acquired with ≤32 phase encoding steps, introducing image reconstruction challenges due to high acceleration factor (≥8). We developed a new parallel imaging technique optimized for image reconstruction of the wavelet transform[3] of original images. Since the wavelet transform is an efficient approach to encoding dynamic information in the temporal domain, dynamic data may be compressed in wavelet space without considerable information loss. This allows for parallel imaging reconstruction from data collected with a high acceleration factor. The final dynamic images are generated using an inverse wavelet transform.

B) Contrast generation from MRI phase dispersion: As a result of the low T_2*, MRI phase dispersion is significant in pulmonary parenchyma. This phase dispersion may be further enhanced by respiration: Air inhalation and alveolar dilation can cause susceptibility changes. By tracking MRI phase dispersion dynamically during free breathing, image contrast may be generated to view respiration-induced susceptibility changes in the lung, providing a non-contrast-enhanced imaging approach to assessing lung function. Here in a dynamic lung image $d(x,y,t)$, MRI phase dispersion $c(x,y,t)$ is evaluated by the square root of sum of squares of phase differences between the voxel (x,y) and its neighboring $(2M+1)\times(2N+1)$ voxels. This is mathematically written as:

$$c(x,y,t) = \sqrt{\sum_{-M<\Delta x<M,-N<\Delta y<N} \{\, phase[d(x,y,t)] - phase[d(x+\Delta x, y+\Delta y, t)] \,\}^2}\ .$$

The total Fourier spectral power of $c(x,y,t)$ within the respiration frequency range (0.1 Hz~0.8 Hz) provides image contrast in the lung.

For concept demonstration, two healthy volunteers were scanned using a 32-channel cardiac coil array on a 3T clinical MRI scanner. Lung imaging data were collected using a T_1-enhanced ultra-fast gradient echo sequence (FOV 480×376 mm, matrix 240×184, TR/TE 2.4/1.2 ms, flip angle 10°). The same sequence was run twice: In the first run, static images were collected at functional residual capacity (FRC) and (FRC+tidal volume) during breath hold. In the second run, dynamic imaging data were collected with an acceleration factor of 8 and a time length of ~12 s while free-breathing. Phase dispersion $c(x,y,t)$ was calculated with M= 5 and N=5.

Results: Figure 1 shows an example of experimental results. Static images during breath hold were used as references (Figure 1a). In free-breathing dynamic imaging, respiration phases were determined from the motion trajectory of liver boundaries (Figure 1b). We did not observe considerable motion or aliasing artifacts in images reconstructed at all respiration phases. By evaluating phase dispersion of dynamic images, image contrast can be generated to view respiration-induced susceptibility changes in the lung (Figure 1c). From phase dispersion time series (Figure 1d), it can also be seen that regional susceptibility differences reach peaks and valleys at different respiration phases in different regions and respiration cycles.

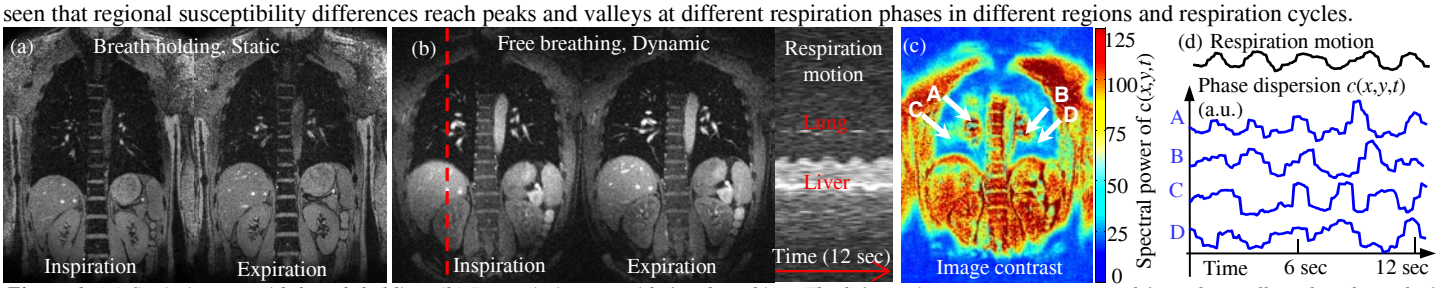

Figure 1*. (a) Static images with breath holding. (b) Dynamic images with free-breathing: The left two images are reconstructed from data collected at the end of inspiration and expiration. The right image is a time trajectory of the red dashed line. This image is used to determine respiration phases from the motion trajectory of liver boundaries. (c) Image contrast generated from the total Fourier spectral power of c(x,y,t) within the respiration frequency range (0.1 Hz~0.8 Hz). (d) Phase dispersion time series c(x,y,t) at different locations: A&B, High phase dispersion region; C&D, Low phase dispersion region; A&C, Right lung; B&D, Left lung.*

Discussion: Compared to previous non-contrast-enhanced techniques[1,2], the presented work generates image contrast from MRI phase instead of magnitude. Since MRI phase dispersion is evaluated in a region with the spatial dimension (~ 2 cm) larger than a motion-induced image shift, there is no need for image registration. This may reduce complexity in clinical applications because image contrast associated with MRI magnitude is sensitive to motion and a motion correction algorithm is typically needed. In addition, the presented work provides an approach to investigating lung function by examining respiration-induced susceptibility changes in every respiration cycle. To view these dynamic changes (Figure 1d), a sufficient temporal resolution is needed. On the other hand, spatial resolution determines the spatial scale in which susceptibility-induced phase dispersion can be evaluated. As a result, there exists the expected tradeoff between temporal and spatial resolution in dynamic data acquisition.

Conclusions: This work demonstrates the feasibility of a non-contrast-enhanced lung imaging technique based on high-speed dynamic data acquisition and phase dispersion analysis. A larger-scale study is underway to investigate how this technique may improve functional lung imaging.

Reference: 1. Bauman G et al., MRM 2009, 62: 656-664. 2. Hatabu H et al., Eur J Radiol 2008; 15: 713-727. 3. Mallat, S, A Wavelet Tour of Signal Processing, Academic Press 2008.