A Method for Visualization of Parenchyma and Airspaces from 3D Ultra-Fast Balanced SSFP Imaging of the Lung at 1.5T

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Target audience. Physicists and physicians interested in lung imaging methods.

Purpose. Only recently, a Fourier decomposition (FD) method was suggested to extract perfusion and ventilation information (parenchyma density) from a time series of co-registered 2D images [1]. Generally, FD requires dynamic sampling with high temporal resolution and nonrigid image registration, currently limiting this technique to 2D only. Here, we introduce a simple method to visualize regional parenchyma density (ventilation) directly and in 3D using high-resolution isotropic ultra-fast balanced steady state free precession (bSSFP) scans at 1.5T acquired within a single breath-hold.

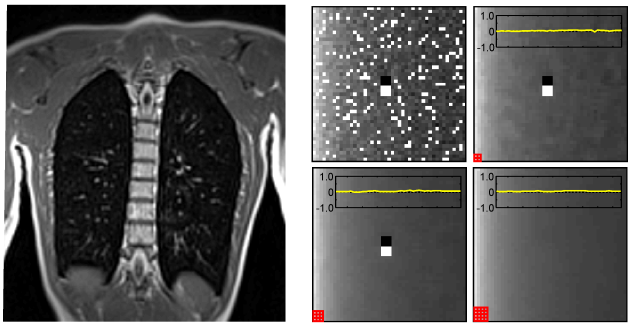

Fig. 1: (left) Coronal sample image from a 3D bSSFP scan showing sparse high intensity voxels referring to lung vasculature. (right) 3D median filtering with variable kernel size (N = 2, top right; N = 3, bottom left; N = 4, bottom right) on a simulation phantom (top left), reflecting the gross features of the in vivo lung tissue signal, namely, parenchyma background signal variation, some noise (5%), high intensity and low structures (centered 3×3×3 squares), and bright "speckle"-like vasculature (see Methods). As expected, median filtering proves to be particularly effective to remove noise without any modification of the background signal variation.

Methods. Recently, a new ultra-fast SSFP imaging approach was introduced to image functional and morphological properties of lung parenchyma in vivo at 1.5 T [2]. The overall achievable CNR between the parenchyma and air should allows the detection of airspaces (i.e., air trapping) in 3D and within a single breath-hold with high sensitivity and specificity. The only interfering structure that overlays and interferes with the parenchyma signal is the lung vasculature (see Fig. 1). Typically, however, the volume density of the vasculature can be assumed to be sparse within the lung volume, giving it a "salt & pepper" or rather "speckle" like appearance. Generally, median filtering should be particularly effective in removing this type of "noise", whilst preserving edges for a given, fixed filter size (N×N×N). To this end, a numerical phantom was evaluated, comprising a monotonic background signal variation (reflecting parenchyma density), overlaid by (i) noise (parenchyma SNR ~ 10), (ii) low and high intensity structures (3×3×3 voxels; mimicking airspaces and larger structures), and (iii) sparse high intensity speckle-like vasculature (10% volume density). In vivo images were acquired with an ultra-fast bSSFP protocol within a single breath-hold (2.5mm isotropic resolution, TR = 1.08 ms, TE = 0.42 ms, 1776 Hz/Pixel bandwith, flip angle of 20°, 18 seconds scan time; see [2]).

Results & Discussion. Median filtering proves to be particularly effective to remove noise and vasculature in the simulation (see Fig. 1): background signal variation is maintained without noticeable bias (the yellow curve represents the normalized deviation between the true variation and the filtered one), whereas high intensity pixels and noise are efficiently removed. Large scale structures (e.g., 3×3×3) are preserved unless the size of the filter exceeds the size of the structures (that is, for N > 3). Sample images from an in vivo 3D bSSFP scan are shown in Fig. 2a. Vasculature appears as a sparse structure (Fig. 2a) that can be efficiently removed using N = 4 median filtering, to reveal a homogeneous parenchyma density (Fig. 2b), as well as small hypointense structures corresponding to the air within the trachea and primary bronchi (Fig. 2c).

Conclusion. A new post-processing method for the extraction of parenchyma density (ventilation) was introduced. This method may be of special advance for imaging many pulmonary diseases in which an inhomogeneity of regional parenchyma density might be expected, such as emphysema, chronic obstructive pulmonary disease, cystic fibrosis, or pulmonary hypertension.

References. [1] Bauman G et al. Magn. Reson. Med. 2009; 62: 656-664. [2]. Bieri O. Magn Reson Med. 2013 doi: 10.1002/mrm.24858

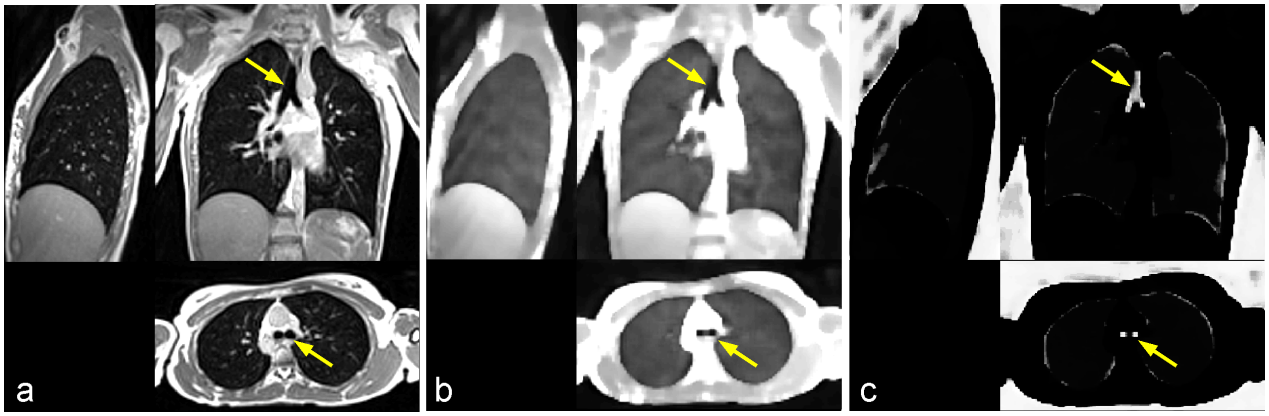

Fig. 2: (a) Sagittal, coronal, and axial sample images from a 3D ultra-fast bSSFP breath-hold scan of the lung at 1.5T. (b) Corresponding median filtered images, using a 4×4×4 filter size. Vasculature is efficiently removed but large scale structures, such as the trachea and primary bronchi (yellow arrows) are preserved (please note that the windowing was adapted to accentuate the signal difference between background noise (i.e., air) and parenchyma. (c) Reversed grayscale images of median filtered images shown in (b) to highlight airspaces.