# Self-gated time resolved volume (4D) imaging of the human lung under free breathing

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**Introduction** Large individual variability of lung tumor displacement and motion patterns has been reported (1, 2). Therefore, time resolved three dimensional (4D) lung imaging in high spatial resolution is required for the individual definition of safety margins in motion adapted radiotherapy planning. In this work, a DC signal acquisition (3) implemented into a 3D FLASH sequence in combination with quasi random sampling (4) was used for the reconstruction of multiple three dimensional respiratory phases (4D lung imaging). All the acquired data were used for the reconstruction of various respiratory phases from expiration to inspiration, increasing the scan efficiency of retrospective respiratory gating.

**Materials and Methods** Measurements were performed on a 1.5 T clinical MR scanner using a spine matrix in combination with a six-channel phased-array body matrix. Volunteer: 44 repeated measurements with an asymmetric echo, TE/TR/$\alpha$ = 0.8ms/2.6ms/8°, matrix: 256x256x64, FOV =500x500x250mm$^3$, resolution 3.9x3.9x3.9mm$^3$, total acquisition time = 15 min. Patient: 18 repeated measurements with an asymmetric echo, TE/TR/$\alpha$ = 0.94/3.3/5°, 256x136x80, FOV = 420x223x230mm$^3$, resolution 1.6x1.6x2.9mm$^3$, total acquisition time = 11 min. The coil element with largest DC signal variations due to respiratory motion was selected for navigation. The DC signal was divided into different gating windows for data acceptance corresponding to various respiratory phases from end expiration to end inspiration (Figure 1). Finally, 3D data sets for various gating windows representing different breathing states were reconstructed retrospectively resulting in a 4D data set. Multiple accepted k space lines within one gating window were averaged and missing lines, due to data rejection, were reconstructed using iterative GRAPPA (5).

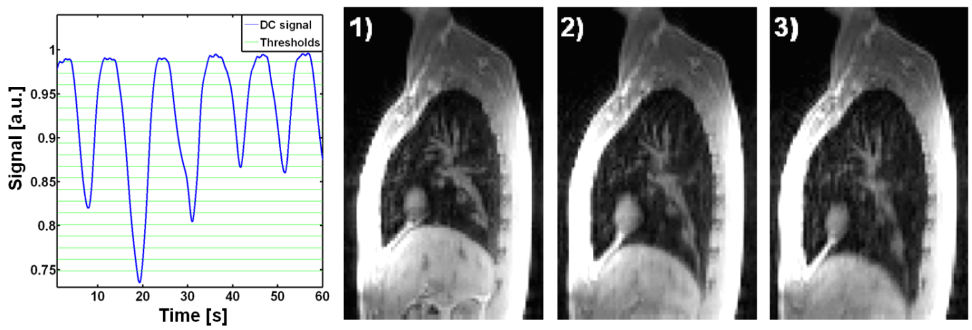


*Figure 1: Volunteer examination. Left: DC signal time course and multiple gating windows Right: Sagittal partition of various respiratory phases: 1) expiration 2) intermediate state 3) inspiration*

**Results** Figure 1 (left) shows the time course of the DC signal that was used for gating of the volunteer experiment. Periodic respiratory variations can be seen. Local maxima are corresponding to respiratory phases of expiration and local minima to respiratory phases of inspiration. Additionally, the various gating windows for data acceptance are displayed (green). Three different reconstructed respiratory phases of a sagittal partition are shown on the right: 1) expiration, 2) intermediate (between expiration and inspiration) and 3) inspiration. The change in the position of the diaphragm and adjacent vessels due to breathing can be seen. Figure 2 shows reconstructed partitions in expiration (left column) and inspiration (right column) of the patient examination. A change in the location of the tumor in both orientations (line and arrow) can be observed due to breathing.

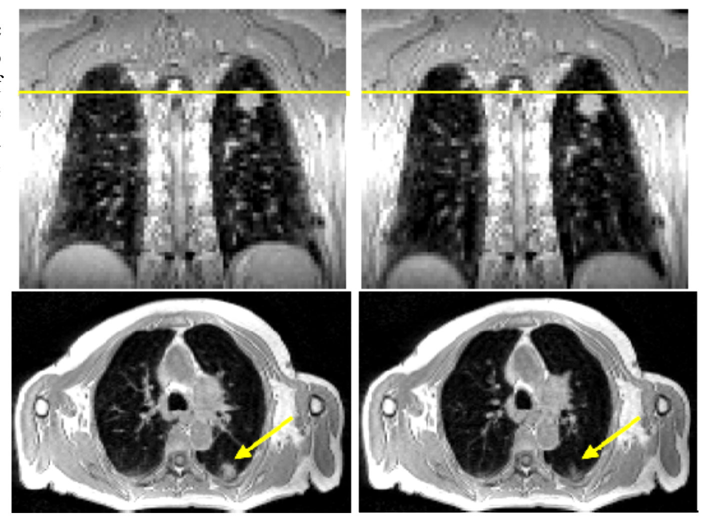

*Figure 2: Patient examination: Tumor displacement between expiration (left) and inspiration (right)*

**Discussion** In this work, volunteer as well as patient experiments under free breathing conditions were performed. It is demonstrated that volume data sets of different respiratory phases can be reconstructed retrospectively using a self-gated randomized sampling scheme. This can be used for the individual assessment of respiratory mechanics or tumor displacement due to breathing and allows for individual motion adapted radiotherapy planning. Because all of the acquired data is used for the retrospective reconstruction off various respiratory phases the scan efficiency is improved. The quasi random sampling leads to a very uniformly under sampling of missing lines in k-space due to the gating process. Accordingly, the distribution of missing lines in k-space is also very regular, increasing the stability of parallel imaging reconstruction.

**References**

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