New strategy of improving the image quality of respiratory-gated Projection Acquisition using 3D k-space spiral trajectory

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Target Audience: MR physicists and radiologists

Purpose: Although projection acquisition (PA), which fills in k-space data with radial spokes, was the first k-space trajectory, it had not been widely used for the time being due to sensitivity to B_0 inhomogeneity and gradient nonlinearity. Thanks to the advance of MR technology, PA recently revived and its advantages were appreciated again such as less sensitivity to motion and a shorter echo-time (TE) without phase encoding. Such advantages motivated most of ultrashort TE (UTE) imaging techniques to employ PA as their basic sampling strategy (1, 2, 3). Thus, it was very natural the first application of the original UTE technique (1) was lung imaging, where some challenging issues exist due to T_2^* shortening and respiratory motion. Although PA intrinsically offers reduced motion artifacts, respiratory gating is preferable for a better image quality in many cases of lung studies. When 3D PA is used with the respiratory gating and parts of projections are selected below/above a certain threshold of the respiration phase, non-uniform regions appear on a sphere in the 3D k-space trajectory (4), which may cause some streak artifacts and blurring in images. In this study, we show that increasing the number of interleaves can practically be a good and easy way to avoid this issue when filling in 3D k-space with a spiral trajectory, demonstrating the results of simulation and human lung imaging at 3T.

Methods: To implement a 3D spiral k-space trajectory with interleaves, we first upgraded the algorithm previously proposed by Stehning et al. (5) so that the number of divided polar angles (θ) can increase when the number of interleaves increases, as was not in the original one (Figs. 1a and b):

$$G_z(p,i) = \left(\frac{p_{max} * i_{max}}{2} - (p+i-1)\right) / \left(\frac{p_{max} * i_{max}}{2}\right),\ \varphi = \sqrt{\frac{2 \cdot p_{max} \cdot \pi}{i_{max}}} \cdot \sin^{-1}\left(G_z(p,i)\right) + \frac{2 \cdot i \cdot \pi}{i_{max}},\ \theta = \cos^{-1}\left(G_z(p,i)\right), \quad [1]$$

where $p = p^{th}$ view in a spiral, $i = i^{th}$ interleave, p_{max} = # of views in a spiral, i_{max} = # of interleaves, φ = azimuthal angle, and θ = polar angle. Using Eq. [1], simulation was performed for comparing the 3D k-space trajectory when $i_{max} = 1$ and $i_{max} = 100$. The respiratory-gated data were selected for both cases and their k-space trajectories were plotted in 3D, where we used the respiratory-gating signal obtained from the experiment of human lung imaging (Fig. 2). The total number of views (= $p_{max} \times i_{max}$) was 30 k in simulation. Human lung imaging was performed at 3T (Siemens Magnetom Trio, Erlangen, Germany) with respiratory gating using the device designed by our group. A recently proposed 3D gradient-echo-based UTE sequence, which is called CODE (COncurrent Dephasing and Excitation) (6), was used for experiment. Scan parameters were as follows: TE/TR = 0.14 ms/3 ms, FOV = 396 mm, FA = 5°, BW = 530 Hz/pixel, # of projections (or view) = 160 k, and scan time = 8 min. Given a total number of views, two experiments were performed with the number of interleaves (i_{max}) set to be 1 and 500, respectively. The number of data selected below the gating threshold was 55% of the total number of views. Image was reconstructed offline with a home-built MATLAB (Mathworks, R2011a) program using gridding algorithm, for which a Kaiser-Bessel kernel function was used for interpolation.

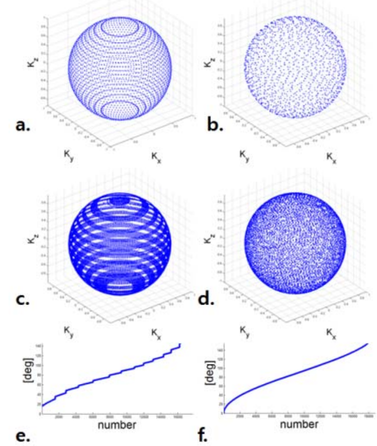

Fig. 1. (a - d) 3D k-space spiral trajectories: (a) by the original algorithm (b) by the upgraded one, # of views = 3 k for (a) and (b). When (c) $i_{max} = 1$, (d) $i_{max} = 100$. **(e - f)** Plots of θ versus the respiratory-gated views: when (e) $i_{max} = 1$, (f) $i_{max} = 100$.

Results: As shown in Figs. 1c and d, the simulation shows that the 3D k-space trajectory was fairly uniform overall on a sphere when $i_{max} = 100$, whereas it appeared non-uniform when $i_{max} = 100$. In Fig. 1e and f, this difference was represented in another way, i.e., by plotting θ versus the respiratory-gated views. While the curve with $i_{max} = 100$ was continuous in a whole range of the gated views, the curve with $i_{max} = 1$ appeared to be discrete. Figure 3 shows the results of human lung imaging. In the case that $i_{max} = 1$ (Figs. 3a and c), streak artifacts were seen in both sagittal and axial images (white arrows) and some blurring occurred at the diaphragm boundary (red arrows). In contrast, when $i_{max} = 500$ (Figs. 3b and d), the streak artifacts as well as blurring almost disappeared and some pulmonary vessels were more clearly identifiable in the sagittal image (yellow arrows).

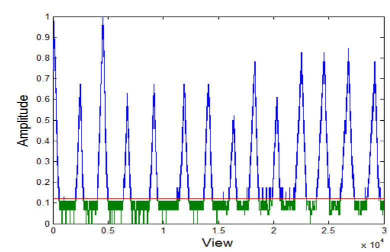

Fig. 2 Respiratory-gating signals obtained from the experiment of human lung imaging. Red line is the gating threshold.

Discussion and Conclusion: A new and simple strategy of improving the image quality of respiratory-gated PA data was proposed here when using a 3D spiral trajectory to fill in k-space. Based on the gradient-view generation algorithm we upgraded, we showed by simulation and experiment that a more uniform k-space trajectory can be obtained by increasing the number of interleaves, thereby removing streak artifacts as well as blurring due to the non-uniformity of k-space trajectory. Considering the wide use of a 3D k-space spiral trajectory with interleaves, it is expected that this method can be useful in practice.

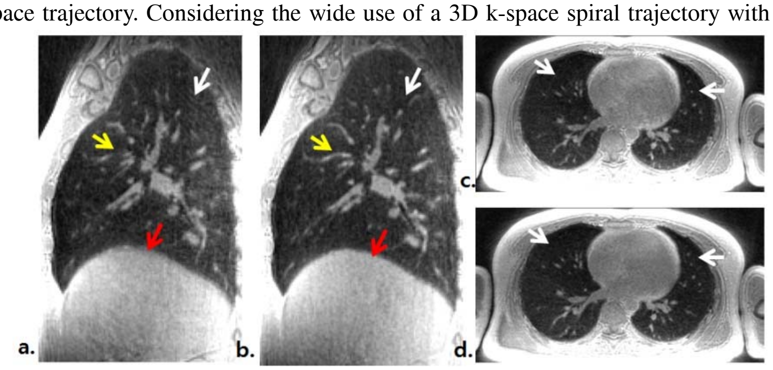

Fig. 3. Sagittal (a and b) and axial images (c and d) of human lung from experiment. (a) and (c) were obtained with $i_{max} = 1$, (b) and (d) with $i_{max} = 500$.

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