Improved through slice resolution in continuously moving table MRI by using a modified helical trajectory

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Introduction: Initially introduced in computed tomography (CT), continuously moving table (CMT) imaging has become a new approach to overcome the limited FOV in MRI. Potential applications of this technique are whole-body screening or MRA. Furthermore, it enables the use of short bore magnets, as only a slim slice in the isocenter needs to be excited. Axial encoding is obtained by the table movement. One of the first experiments on CMT was helical MRI, presented in [1, 2]. It uses a radial readout with a linearly increasing projection (a.k.a. spoke) angle. Each spoke originates from a slice that is slightly shifted along the slice (z) direction (by the distance dz), leading to a trajectory shaped like a helix. With no preferred slice position, arbitrary slice positions can be reconstructed. However, analogous to CT, helical MRI data requires a linear interpolation (LI) of spokes with the same angle. This reduces artifacts, provoked by the table movement, but it also smears details into neighboring slices. In this work, the angular sampling scheme was modified based on the golden ratio presented in [3]. Thus k-space is covered almost uniformly at any time. This allows to vary the number of spokes during the sliding window reconstruction or to apply a KWIC (K-space Weighed Image Contrast) filter [3], both of which improve slice sensitivity.

Methods: Standard and modified helical trajectories were implemented on a Siemens Avanto 1.5 T system using a TrueFISP imaging module. In this work the table movement was simulated by shifting the position of the slice excitation for each spoke by adapting the frequency of the RF pulse. Three reconstruction methods were compared: sliding window (SW), linear interpolation (LI) and KWIC filter. The performance of the different reconstruction methods was tested on a phantom. Additionally, the slice shift (slice thickness TH per 192 projections and per 64 projections) was altered to examine undersampling effects and to decrease the measurement time. The methods were also tested in vivo for the brain and abdomen during free breathing.

Results: Fig. 1 shows through plane images (y,z), comparing the standard and modified helical trajectory. The SW method (Fig. 1a) cannot fully resolve the finer details (see arrows). This is partly improved by the LI (Fig. 1b), but it also leads to blurring. Golden ratio based trajectories resolve fine structures better (Fig. 1c). With slower slice shifting (0.6 cm/s), the resolution is limited by the excitation thickness. In this case, SW and KWIC show comparable results. For a 3 times faster slice shift (1.9 cm/s), KWIC filtering shows only a slightly reduced resolution (Fig. 1d), while the SW method increases the smearing (not shown here).
Similar results can be seen in Fig. 2 for the brain. In Fig. 2a a moderate slice shift was applied. The in plane image quality does not differ from a 2D acquisition without moving table. With the 3 times faster slice shifting surrounding regions contribute to the selected slice in the SW reconstruction (Fig. 2b). At the faster slice shifting, the improvement of KWIC filtering can be observed (Fig. 2c): it is able to keep the z-resolution comparable to Fig 2a. It can be noted, that images with fast slice shifting show an altered TrueFISP contrast. This can be explained, because more fresh spins are moved into the excitation region. For these spins, the true steady state is not yet attained. Finally, the trajectory was tested on the abdomen (Fig. 3) under free breathing conditions. Both SW and KWIC (233 projections wide) were able to freeze the respiratory motion. Artifacts that appear in standard helical MR or CT without LI reconstruction were not observed. Although KWIC can produce streaking at strong breathing, it still yields an improved through plane resolution.

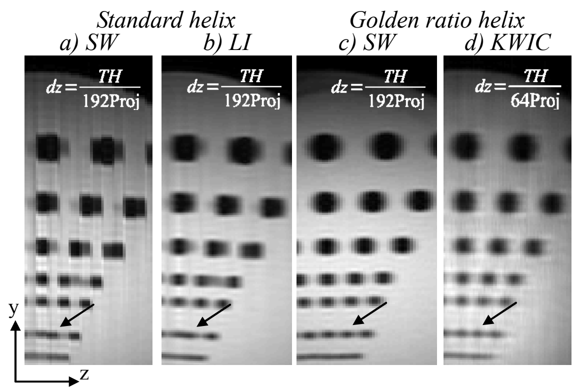

Fig. 1: Comparison of the through plane resolution; N_{read}=128, TH=5 mm

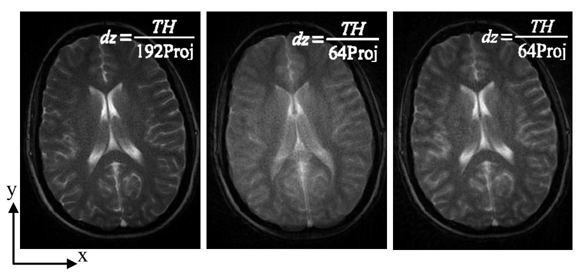

Fig. 2: Effect of faster slice shifting: SW (b) and KWIC filtered (c) reconstructions are compared with SW reconstruction at slower slice shifting (a); N_{read}=384, TH=9 mm

Conclusion: Helical trajectories cover three dimensional regions without any gaps, by exciting the slices at shifted positions. The golden ratio based angular profile results in a few advantages, because two successive spokes cover a completely different region of k-space. This allows further undersampling, which results in a faster table speed and shorter acquisition times. Combined with a KWIC filter, the through plane resolution at higher slice shifts is maintained, while streaking is reduced. Table movement and object motion have less effect on image quality and thus linear interpolation becomes obsolete.

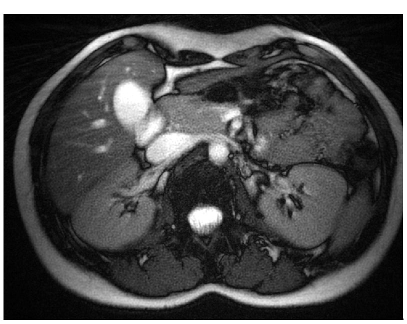

Fig. 3: Abdomen with KWIC, free breathing.

N_{read}= 384, TH= 9 mm,

$$dz = \frac{TH}{192Proj}$$

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References:
[1] Rasche, et al. Proc. 13th SMRM 1994; 787.
[2] Shankaranarayanan, et al. MRM 2003; 50:1053-1060.
[3] Winkelmann, et al. IEEE Trans Med Imaging. 2007; 26(1):68-76.