A COMPARISON OF SPIRAL-OUT, SPIRAL-IN/OUT AND RADIAL BALANCED SSFP SEQUENCES FOR DYNAMIC CARDIAC IMAGING

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Introduction: Cartesian and radial balanced SSFP (bSSFP) sequences are widely used clinically for dynamic cardiac imaging. Dynamic spiral sequences have been used in many research studies, but clinical adoption has been slow. One goal of this study is to compare radial and spiral dynamic balanced SSFP scanning. Radial bSSFP reduces scan time through k-space undersampling, whereas spiral bSSFP reduces scan time primarily by scanning more of k-space in a given TR, with undersampling possible using variable-density scanning. The other goal of this study is to develop a new spiral-in/spiral-out bSSFP pulse sequence to achieve flow compensation through symmetry and to exploit the bSSFP refocusing mechanism at TE = TR/2. We compared this new sequence to radial bSSFP and spiral-out bSSFP with flow-compensated rewinders.

Methods: For spiral-out bSSFP, we used a triangle-based rewinder simultaneously nullifying the 0th and 1st gradient moment described in [1]. For the spiral-in/spiral-out bSSFP sequence, we design the gradients as follows: (1) Generate a constant or variable density spiral-out gradient using [2]; (2) Generate a time optimal transition gradient following the spiral gradient to move the k-space trajectory to the origin and reduce the gradient to zero at the same time; and (3) Time reverse the previous gradients and put the reversed gradients in front so that the k-space trajectory is at the origin at the midpoint of the entire gradient. Figure 1 shows the gradient and the corresponding trajectory of one interleaf. Due to symmetry, the 0th and 1st gradient moments are automatically nulled at the end of TR without further rewinders.

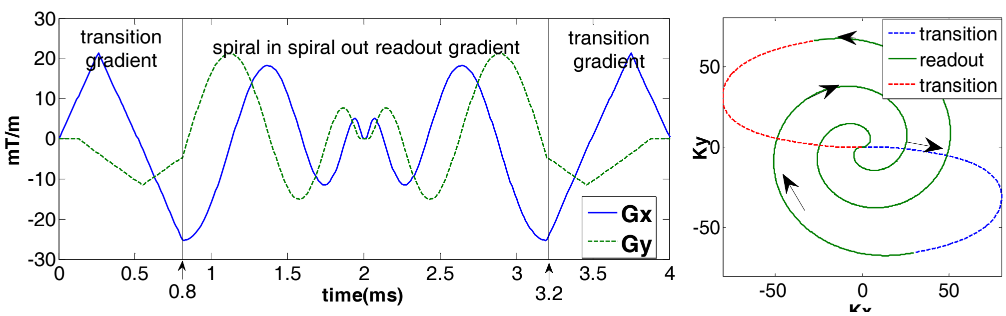

Fig.1 2D spiral in/out SSFP gradient waveforms (left) with the corresponding k-space trajectory (right). The arrows on the k-space trajectory indicate the direction of the trajectory.

The same slice is selected for all three sequences with slice thickness = 8 mm and FOV = 340 mm. Other parameters are given in Table 1. To improve the spiral data acquisition efficiency and reduce the aliasing artifacts, a variable density design [3] was used for both spiral balanced SSFP and spiral in/out balanced SSFP.

	TR (ms)	TE (ms)	Inter-leaf	Resolution (mm)	Total time(ms)
Radial	2.36	1.18	48	2.7*2.7	113
Spiral out	4.70	0.99	26	2.5*2.5	122
Spiral in/out	5.00	2.50	24	2.4*2.4	120

Table 1 sequence parameters. Interleaf and total time correspond to one complete image

In reconstruction of both the spiral balanced SSFP and the spiral in/out balanced SSFP, we used the anisotropic delay model to get a more accurate k-space trajectory. For all of the three sequences, we used the 2x view sharing by sliding window technique.

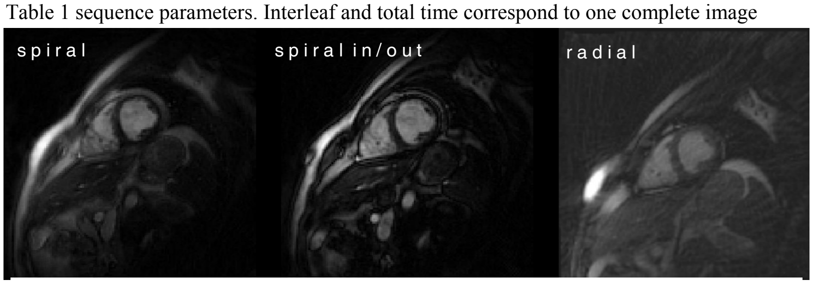

Fig. 2 breath hold short axis images of the heart from spiral, spiral in/out and radial SSFP sequences.

Results: Imaging experiments were performed on healthy volunteers at 1.5T. Figure 2 shows short axis cardiac images from three sequences. Compared to the radial image, both spiral images have better SNR and contrast and fewer aliasing artifacts in general because the efficiency of spiral scanning requires much less undersampling. Comparing the spiral-out and spiral in/out images, spiral in/out has higher blood-pool to myocardial contrast but more flow artifacts from the aorta and a dark band artifact in the lateral wall. One cardiologist blindly reviewed the images/videos from the spiral-out, spiral in/out and radial bSSFP studies. The spiral-out and spiral in/out scans were judged to have better image quality than radial.

Conclusions: Dynamic spiral balanced SSFP sequences take advantage of spiral data acquisition efficiency and increase SNR and contrast, but suffer more from off-resonance artifacts because of their longer TR. The new spiral in/out bSSFP sequence yields improved contrast, but appears to have more data inconsistency artifacts. The TR in spiral sequences can be made shorter by increased undersampling or using parallel imaging. Dynamic parallel Cartesian bSSFP is another alternative, so rapid and accurate non-Cartesian parallel reconstruction will be needed for radial and spiral bSSFP sequences to be faster than Cartesian alternatives.

References:

[1] Nayak KS, et al. MRM 53:1468–1473, 2005 [2] Meyer CH, et al. ISMRM 1996 [3] Tsai CM, et al. MRM 43:452-458, 2000
[4] Irarrazabal P, et al. MRM 35:278-282, 1996