A spiral spectral-spatial RF pulse with rotated variable density k-space trajectory

W. Deng[1], and V. A. Stenger[2]

[1]Medicine, University of Hawaii, Honolulu, HI, United States, [2]Department of Medicine, University of Hawaii, Honolulu, HI, United States

Introduction: A spiral spectral-spatial RF pulse achieves 2D spatial localization and frequency selection simultaneously. This has been shown to be useful for achieving good spectral selectivity in slices containing spatially dependent chemical shifts (1). Unfortunately, the length of the spiral is limited to $T=1/\Delta f_S$ where Δf_S is the stop-band frequency width (i.e. T=1.1 ms for Δf_S=880Hz at 3T). Variable density spirals have been shown to be useful for increasing sampling power at the expense of increased aliasing (2-4). We present a variable density spiral spectral-spatial pulse with periodically rotated gradients for improved spectral and 2D spatial localization at 3T. Significantly reduced slice aliasing outside the excitation field of view (FOX) was found.

Theory: The small-tip-angle approximation (5) provides a Fourier picture for the design of multi-dimensional RF pulses. Fig. 1 (a) shows an example spiral spectral-spatial RF pulse. This pulse consists of eight sub-pulses, each of which excites a 2D spatial profile, such as a uniform disk. The periodicity T of the sub-pulses produces the spectral selectivity. The Fourier transformation of the overall RF envelope gives the frequency pass-band Δf_P, which can be centered at either the water or lipid frequencies. Unfortunately, the spiral length T limits the excitation resolution and FOX of the 2D profile. Variable density spirals can be used to over-sample the center of k-space such that there is an increase the FOX at a small expense of increased aliasing. Furthermore, by rotating the spiral gradient waveforms, as shown in Fig. 1 (b), the pass-band at zero frequency is further over-sampled and aliasing of the 2D profile is dispersed throughout the frequency band.

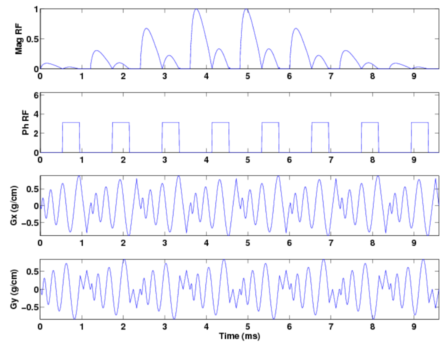

Figure 1. (a) From top to bottom, magnitude and phase of B1 waveforms, gradient waveforms in x and y directions.

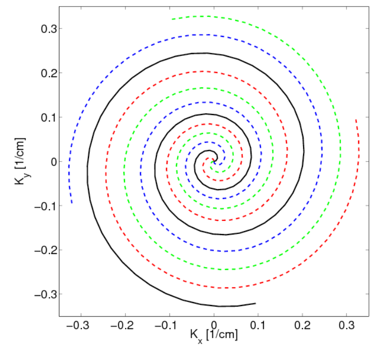

Figure 1. (b) Un-rotated (solid line) and rotated (dashed line) variable density spiral k-space trajectories.

Methods and Results: Experiments were carried out on a Siemens 3T whole body scanner. Images of a water/lipid phantom (Fig. 2 (a)) were acquired with a spin-echo pulse sequence (TE/TR=50/1000ms, 90^0 flip angle, FOV=16cm). Variable density spiral spectral-spatial pulses similar to that in Fig. 1 (a) were used (FOX=12cm, 2cm resolution, T=1.1ms, Δf_S=880Hz, Δf_P=250Hz). The variable density k-space trajectories were similar to Fig. 1 (b) with a factor of two over-sampling in the center. Each spiral gradient was successively rotated 90^0. In Fig. 2 (c) and (d), it is seen that both rotating the gradients and variable density spirals reduce aliasing outside of the original FOX. Combining these two techniques (e) we can acquire an image with 83% reduced aliasing outside of the FOX compared to (b). *In-vivo* lipid images of the calf in a human volunteer were also acquired (TE/TR=30/1000ms, 90^0 flip angle, FOV=12cm). In these scans FOX=FOV to deliberately fold over aliasing into the FOV (Fig. 3). The image acquired with the rotated variable density spiral pulse in (b) has reduced aliasing compared to (a), which was acquired with standard spirals.

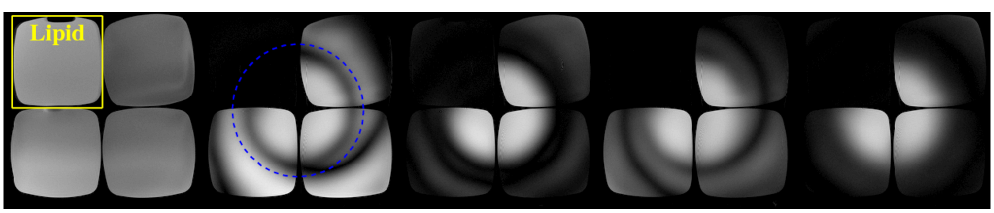

Figure 2. **(a)** **(b)** **(c)** **(d)** **(e)**

(a) Axial image of water/lipid phantom. **(b)** Same image acquired with a standard spiral spectral-spatial pulse. The pulse was designed to excite a circle (the FOX is approximately shown by the dashed circle). **(c)** Image acquired with a uniform spirals and rotated gradients. **(d)** Image acquired with a variable density spirals. **(e)** Image acquired with a variable density spirals and gradient rotation. Note the large decrease in aliasing outside the FOX.

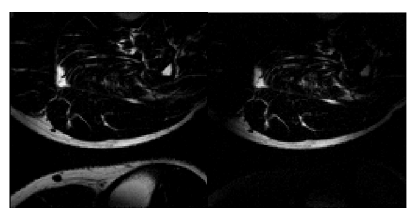

Figure 3. **(a)** **(b)**

(a) Axial lipid images of the calf using a uniform spiral pulse and **(b)** with a rotated variable density spirals. Note the reduced aliasing in (b).

Conclusions: We have shown that variable density spirals can be used to effectively reduce aliasing in the spectral-spatial 2D excitations. Furthermore, rotating the gradients allows for further reduction of aliasing because the aliasing energy gets displaced throughout the frequency band. This shifting of aliasing in frequency space is similar to the UNFOLD technique (6) where periodic gradient rotation is used for improved temporal resolution in dynamic imaging.

References: (1) G. Morrell and A. Macovski, MRM 37:378-386 (1997). (2) D. M. Spielman *et al.* MRM 34:388-394 (1995). (3) V. A. Stenger *et al.* MRM 50:1100-1106 (2003). (4) J. Pauly *et al.* JMR 82:571-587 (1989). (5) B. Madore *et al.* MRM 42:813-828 (1999).

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