Noncontrast MRA using Spiral Refocused Turbo Spin Echo

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Introduction: Flow-independent angiography is a type of noncontrast-enhanced imaging that relies on the NMR properties of tissue, rather than flow, to generate contrast. RARE-type sequences are capable of generating contrast between blood and surrounding tissue based on T_2 differences, but conventional RARE sequences have a non-zero first moment at the RF pulses and at odd echoes, and are therefore susceptible to flow-related artifacts and signal loss. An alternative technique combines the increased signal provided by the 180° refocusing RF pulses of RARE and the better flow performance of the refocused gradients and phase alternation of balanced SSFP. Blood-background contrast is then provided by the T_2 differences between blood and background muscle tissue. To separate arteries from veins, we take advantage of the fact that the apparent T_2 of blood is dependent on its oxygenation status and on the frequency of refocusing in a rapidly-refocused sequence: as the frequency of refocusing is decreased, the venous signal is suppressed more than the arterial signal. Here, we extend the Cartesian-scanning sequence we previously presented [1] to a stack-of-spirals 3D acquisition in order to increase echo spacing while maintaining reasonable scan times.

Methods: The sequence implemented a stack-of-spirals acquisition obtained via a RARE-type echo train, as shown in Figure 1. A 12-ms duration spectral-spatial excitation pulse was used to excite water only, followed by an echo train whose maximum length was 24. The spiral readout had 4.8 ms duration. Both spiral gradients were rewound between each refocusing pulse such that the zeroth moments were nulled at each RF pulse. This, combined with phase alternation of the RF pulses along the echo train, imparts a degree of flow insensitivity to the sequence, allowing arteries to be depicted based on the T_2 differences without subtraction of systolic- and diastolic-phase images and without preparatory pulses.

A 3D dataset was acquired on a Siemens 3-T Trio scanner (Siemens Medical Solutions) with peripheral MRA coils placed anteriorly and laterally, and a spine coil placed posteriorly. The FOV was 400 x 400 x 120 mm^3, oriented coronally. Sequence parameters were: TR/TE/Echo Spacing = 3000/230/20 ms, and 24 interleaves were used for each 3D phase encoding. No gating was used during acquisition. A Cartesian rTSE scan with fat suppression was also performed with the same FOV and sequence parameters: TR/TE/Echo Spacing = 3000/228/3.4 ms.

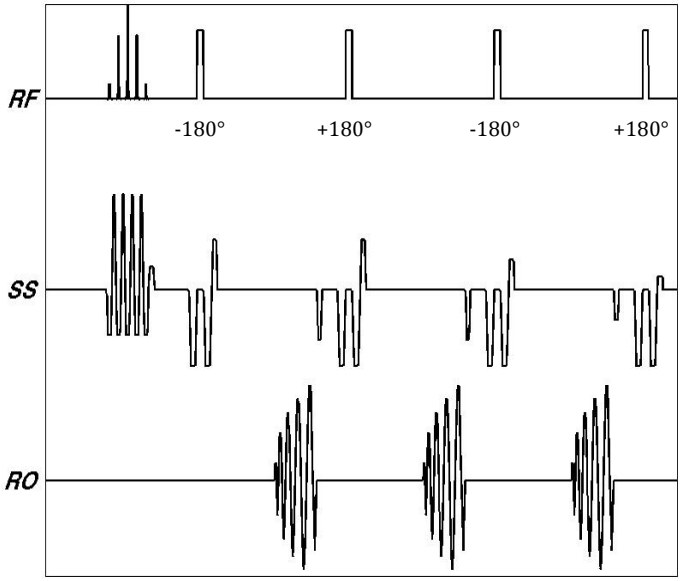

Figure 1. Spiral refocused Turbo Spin Echo.

Results: Figure 2 shows maximum intensity projection images of the result using the spiral-based sequence on the right, and is contrasted with a Cartesian rTSE scan on the left. Bright-blood images were successfully reconstructed without subtraction.

Discussion & Conclusions: Long echo spacings are desirable in rTSE scans to reduce venous contamination of the images; spiral readouts efficiently sample k-space and thus may be used to extend echo spacing without increasing overall scan time. To further improve efficiency, spiral-in / spiral-out gradients, variable density spiral imaging, and parallel imaging may be used.

While the spiral readout gradients were rewound between each RF pulse, the first moment of each readout gradient was not zero; however, the first moment remains small on each readout axis, and thus imparts little motion sensitivity to the sequence. The crushers surrounding each refocusing pulse also result in a non-zero gradient moment in the 3D phase encoding direction; however, as the majority of flow is in the anterior-posterior direction in the periphery, this had little observable effect in regards to flow-related signal loss or artifacts. In these images, the synovial fluid in the knees appears bright due to its long T_2. The application of an inversion pulse prior to the excitation would allow suppression of this fluid based on its T_1.

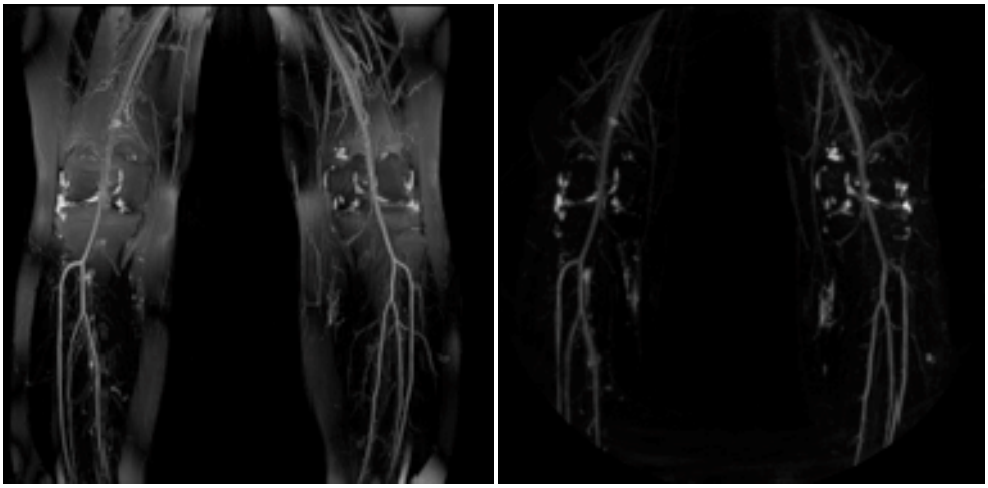

Figure 2. Cartesian rTSE angiogram (left) versus spiral rTSE angiogram (right).

[1] Fielden SW et al. ISMRM 2009 #1877.