Improved venous suppression in non-contrast MRA with the spiral turbo spin echo sequence

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Purpose: Flow-independent angiography is a type of non-contrast-enhanced imaging that relies on the NMR properties of tissue, rather than flow, to generate contrast. 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 upon the frequency of RF pulses in a rapidly-refocused sequence* [1]. Here, we present several improvements to the stack-of-spirals 3D acquisition proposed in [2] in order to increase resolution and reduce scan time.

Methods: The spiral TSE sequence is shown in Figure 1. The trajectory consists of a stack-of-spirals, allowing us to perform off-resonance correction in 3D by executing 2D off-resonance correction slice-by-slice [3]. The same interleaf from each 3D phase encode is acquired in a single echo train, before advancing to the next. Partial k-space coverage of 70-100% in the through-plane direction is performed when the effective TE is placed earlier than the mid-point of the echo train.

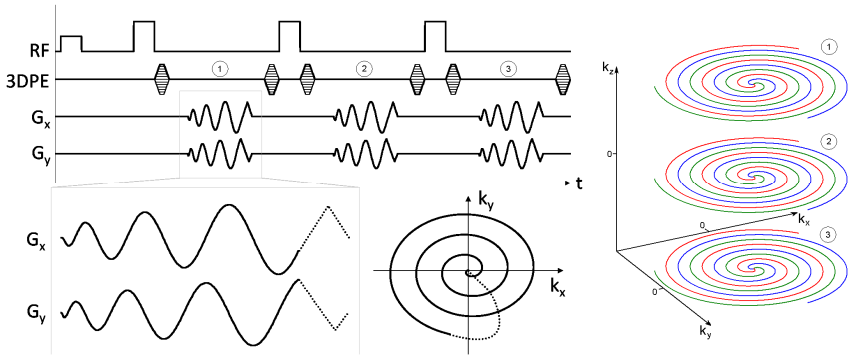

Figure 1. Spiral TSE pulse sequence with spiral-out gradients.

Variable-density gradients with acceleration factors of 2-4 with SPIRiT reconstruction [4] are used in order to improve in-plane resolution. For the abdominal station, slab-selective excitation pulses necessitate multiple averages, allowing the use of redundant spiral-in/out readout gradients which have been shown to be more resistant to blurring due to off-resonance [5].

In 2 male volunteers, thigh-station images were acquired with a range of echo times (55-85 ms) and echo spacings (6.2-11.6 ms) within the echo train in order to demonstrate the contrast properties of the sequence. The number of interleaves was adjusted in each case in order to maintain the same 1.2 mm^2 in-plane resolution.

Results: Figures 2 and 3 show improved background and venous suppression when longer TEs and echo spacings are used, respectively. Figure 4 shows a typical calf-station MIP obtained with this sequence. The scan was acquired on a Siemens 3-T Trio scanner with peripheral MRA coils placed anteriorly and laterally, and a spine coil place posteriorly. The FOV was 400 x 400 x 128 mm^3 with an in-plane resolution of 1.2 mm^2, achieved with 24 interleaves, and a through-plane resolution of 2 mm. Sequence parameters were: TR/TE/Echo Spacing = 3000/200/10 ms. Acquisition time 1:48 min.

Discussion and Conclusion: Blood/muscle contrast is provided in this sequence by choosing a late effective TE (>100 ms). Uniquely, arterial/venous contrast is provided by long echo spacings, rather than flow-based subtraction techniques used in other TSE-based non-contrast angiography methods. The spiral TSE sequence is a fast, non-subtractive technique for peripheral non-contrast angiography.

References:

[1] Wright, MRM (1991) 17:126-40. [2] Fielden, ISMRM 2010, p3788. [3] Chen, ISMRM 2006, p2966. [4] Lustig, MRM (2010) 64:457-71. [5] Fielden, ISMRM 2012, p2415.

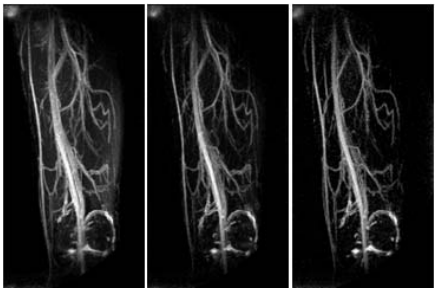

Figure 2. Increasing TE improves blood/muscle contrast. From left to right, images were acquired with TE = 55, 85, 165ms.

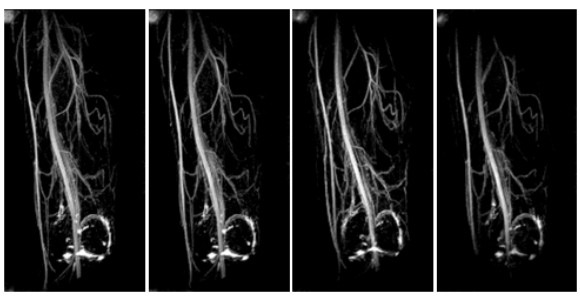

Figure 3. Increasing echo spacing improves artery/vein contrast. From left to right, images were acquired with echo spacing = 6.2, 7.4, 10, 11.6ms.

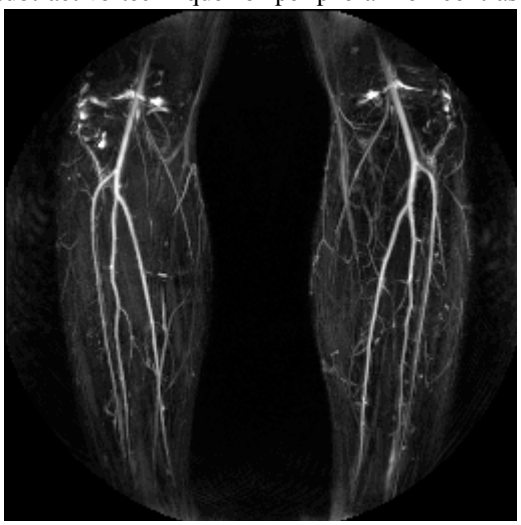

Figure 4. MIP of calf-station of a normal volunteer acquired with spiral TSE sequence.