Non-contrast-enhanced Flow-independent Peripheral Angiography using a 3D Concentric Cylinders Trajectory

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Introduction: Non-contrast-enhanced flow-independent angiography (FIA) exploits intrinsic tissue parameters such as T1, T2 and chemical shift to generate vessel contrast [1]. Unlike flow-dependent methods, FIA can generate stable vessel contrast even with slow flow potentially in the diseased leg. Magnetization-prepared 3D SSFP sequences have been of interest for FIA [2,3], but an important issue with these sequences is artery-vein contrast. Recently, an efficient and robust 3D SSFP imaging sequence using a concentric cylinders *k*-space trajectory was developed [4]. Concentric cylinders offer the following advantages: a) fewer excitations required than a comparable 3DFT sequence; b) robustness to off-resonance effects; and c) inherent centric view-ordering, crucial for magnetization-prepared imaging [4-6]. In this work, the 3D concentric cylinders trajectory was incorporated into a T2-prepared SSFP FIA sequence for scan-time reduction that can be traded off to improve the artery-vein contrast in the lower extremities.

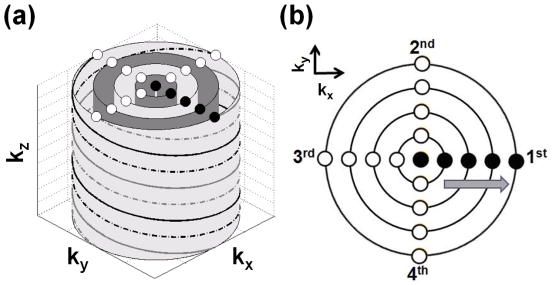

Fig. 1. (a) *k*-space trajectory of 3D concentric cylinders with N_c = 5 cylinders (the radius of the innermost cylinder is 0). N_{intlv} = 4 helical interleaves with N_{rev} = 2 revolutions are shown on the side of the outermost cylinder. (b) Centric-ordered scheme (N_{seg} = 4) viewed from k_z axis. Dots are starting points of interleaves. The collection of black dots represents the 1st segment and the arrow shows the center-out acquisition direction for the 1st segment, which yields a smooth *k*-space weighting.

Methods: 3D concentric cylinders: A 3D concentric cylinders trajectory derives from a 2D concentric rings trajectory [7] by adding a constant G_z gradient during the readout interval. The constant G_z gradient is a key feature that converts the off-resonance behavior from a blur (typical of non-Cartesian trajectories) into a benign geometric shift in the *z*-direction [4-6]. Once the radius (k_{xmax}, k_{ymax}) and the height (k_{zmax}) of the outermost cylinder are chosen based on the desired spatial resolution, the number of uniformly-spaced concentric cylinders (N_c) determines the in-plane FOV, while the number of helical interleaves per cylinder (N_{intlv}) and the number of revolutions for each helical interleaf (N_{rev}) determine the *z*-direction FOV and the number of slices ($N_{slice} = N_{intlv} \times N_{rev}$) (Fig. 1a). This 3D trajectory is well-suited for T2-prepared SSFP sequence in two aspects. 1) It requires a factor of $2N_{rev}$ fewer excitations than a comparable 3DFT acquisition, and 2) *k*-space can be easily divided into several centric-ordered segmentations by collecting helical interleaves at the same angular location from each cylinder (Fig. 1b).

Pulse Sequence: Figure 2a shows a pulse sequence diagram for the T2-prepared 3D SSFP angiography. The T2-preparation augments the artery-vein and artery-muscle contrast inherent in the SSFP sequence (Fig. 2b). This transient contrast is effectively captured by the centric-ordered segmented acquisition using the 3D concentric cylinders trajectory. The factor of $2N_{rev}$ fewer excitations can be exploited to increase the number of segments (N_{seg}), thereby shortening the readout interval per segment to better capture the contrast created by T2-preparation. Increasing N_{rev} can be also beneficial for purposefully lengthening the TR to improve venous suppression [8].

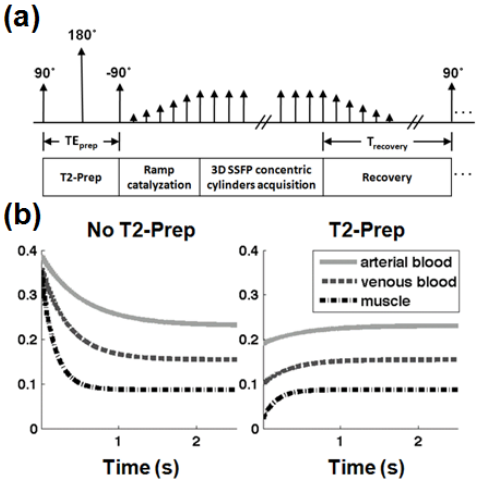

Fig. 2. (a) Pulse sequence diagram. (b) Simulated regular SSFP (left) and T2-prepared SSFP (right, TE_{prep} = 160 ms) transient signal for arterial blood (T1/T2 = 1000/220 ms), venous blood (1000/100 ms), and muscle (870/47 ms).

Results: In-vivo experiments were performed on a GE Excite 1.5 T whole-body scanner with a quadrature birdcage coil. Gradients were designed to provide resolution = 1×1×2 mm^3 and FOV = 26×26×13 cm^3 (matrix size = 256×256×64) using N_c = 128, N_{slice} = 64, N_{intlv}/N_{rev} = 32/2. Readout bandwidth = ±125 kHz was used, which resulted in N_{samp} = 1312 points per interleaf. For water-fat separation, an extended 2-point Dixon method [9] was used with TE = 3.8/6.0 ms, TR = 10 ms, and flip angle = 60°. Adiabatic BIR-4 pulses were used for T2-preparation [10]. *k*-space was divided into N_{seg} = 32 segments with 1 s recovery time between segments, which yielded 1.3 s for each segment. Two phase-cycled datasets were acquired for banding artifact reduction [11]. Total scan time was 6 min. Images were reconstructed by 3D gridding followed by the extended 2-point Dixon method and a maximum-intensity-projection (MIP) with a factor of 2 zero-padding in all three dimensions. Figure 3 shows the coronal MIP images of the calf obtained with no T2-Prep, T2-Prep with TE_{prep} = 80 ms (maximizing artery-muscle contrast), and T2-Prep with TE_{prep} = 160 ms (maximizing artery-vein contrast). The image with T2-prep of TE_{prep} = 80 ms (Fig. 3b) shows a significant suppression of background muscle signal compared to the image without T2-Prep (Fig. 3a). T2-Prep of TE_{prep} = 160 ms further suppressed the residual venous signal (white arrow) as well as the muscle signal with only marginal decrease of the arterial signal (Fig 3c).

Discussion: We demonstrated that the 3D concentric cylinders trajectory is well-suited for the 3D magnetization-prepared FIA method. Compared to other non-Cartesian sequences, implementation is more straightforward and off-resonance correction is not needed. The reduction in number of excitations afforded by the sequence facilitates the use of more imaging segments to better capture the artery-vein contrast created by the T2-Prep. The sequence can be adapted for imaging at 3 T to further improve the contrast by taking advantage of the decreased effective T2 of venous blood. [12]. It can also be combined with other scan-acceleration methods such as variable-density sampling, parallel imaging, and compressed sensing.

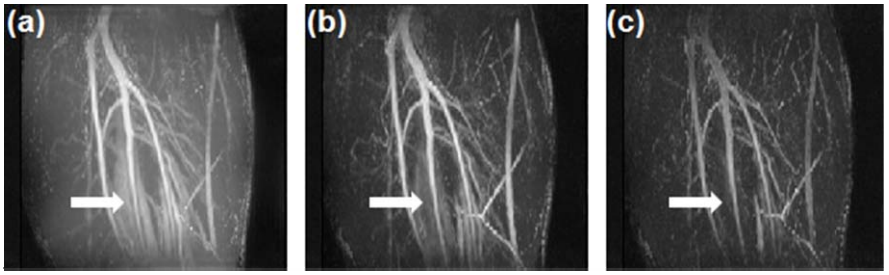

Fig. 3. Coronal MIP images of the calf: (a) No T2-Prep (b) T2-Prep with TE_{prep} = 80 ms (c) T2-Prep with TE_{prep} = 160 ms. White arrows show the degree of venous suppressions.

References: [1] Wright, MRM 17:126, 1991. [2] Brittain, ISMRM, p.1710, 2003. [3] Stafford, MRM 59:430, 2008. [4] Kwon, ISMRM, p.4973, 2010. [5] Mugler, SMR, p.483, 1995. [6] Ruppert, ISMRM, p.208, 2003. [7] Wu, MRM 59:102, 2008. [8] Dharmakumar, MRM 53:574, 2005. [9] Skinner, MRM 37:628, 1997. [10] Nezafat, MRM 61:1326, 2009. [11] Bangerter, MRM 51:1038, 2004. [12] Brittain, ISMRM, p.1710, 2003.