Non-Contrast-Enhanced Flow-Independent 3D Peripheral Angiography with Sliding Interleaved Concentric Cylinders

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Introduction: Non-contrast-enhanced flow-independent angiography (FIA) [1] exploits intrinsic tissue parameters such as T1, T2 and chemical shift, and thereby generates stable vessel contrast even under slow-flow conditions in the lower extremities. Magnetization-prepared 3D SSFP sequences have been of interest for FIA [2,3], but an important challenge with these sequences is artery-vein contrast. In this work, a variation of SLINKY (Sliding Interleaved k_y) [4,5] acquisition was incorporated into a 3D concentric cylinders SSFP FIA sequence [6] to improve artery-vein contrast in the lower extremities by suppressing the venous signal while retaining an arterial flow-independent approach.

Methods: <u>SLINKY with 3D Concentric Cylinders (c-SLINKY):</u> The 3D concentric cylinders trajectory (Fig. 1a) is decomposed into subsets of cylinders and each set is allocated to one slab (Fig. 1b) according to the slab index. The slab location is incremented by a distance d equal to the resolution in the slab direction. By setting the fully-sampled direction k_z as the slab direction (S/I direction), a similar hybrid space of the original SLINKY technique [4,5] can be generated after gridding while artifacts due to k-space amplitude modulation are more distributed over the x-y plane than those of the original 3DFT SLINKY. A linear-phase RF pulse was used to obviate the need of navigator echoes for correcting phase modulation [7].

<u>Pulse Sequence:</u> Figure 1c shows the timing diagram, multiple segments of which are played for each slab. The transient contrast from venous and fat saturation pulses is effectively captured by the centric-ordered segmented acquisition using the 3D concentric cylinders trajectory, which can be also beneficial for purposefully lengthening the TR to optimize oxygen-sensitive SSFP artery-vein contrast [8]. No cardiac triggering was necessary.

<u>Imaging Parameters:</u> *In vivo* experiments on a healthy volunteer were performed on a GE Excite 1.5 T scanner with a quadrature birdcage coil. Gradients for the 3D SSFP concentric cylinders trajectory were designed to provide isotropic resolution = 1.1 mm and FOV = $280 \times 280 \times 26.4$ mm³ (matrix size = $256 \times 256 \times 24$). TE/TR = 3.9/8.2 ms, and flip angle = 60°. k-space of each slab was divided into two segments. In each segment, $T_{readout}$ = 400 ms for 48 TR and $T_{prep} + T_{recovery}$ = 200 ms. A total of 143 slabs were acquired to cover 140 mm in S/I direction. Total scan time was four minutes. Images were reconstructed with 3D gridding followed by a c-SLINKY reconstruction [9] and a maximum-intensity-projection (MIP) with a factor of two zero-padding in all three dimensions. For comparison, MOTSA (Multiple Overlapped Thin Slab Acquisition) [10] images implemented with 3D concentric cylinders were also acquired with matching parameters.

Results: Figure 2 demonstrates that the c-SLINKY acquisition is feasible without severe artifacts in the component slice (Fig. 2a) and is able to depict the lower extremities with a relatively uniform arterial signal and venous suppression through the FOV (Fig. 2b). Another set of results in Fig. 3 shows that MOTSA with a venous saturation pulse improves the artery-vein contrast without loss of arterial signal (3a vs 3b), but the c-SLINKY acquisition distributes the venous-suppression effects more evenly over the FOV and the venetian blind artifacts are mitigated (3b vs 3c).

Discussion: We demonstrated the feasibility of a c-SLINKY acquisition combined with a magnetization-prepared 3D bSSFP sequence to improve artery-vein contrast in the lower extremities. Not relying on arterial inflow and distributing the venous-suppression effects evenly over the FOV, this SLINKY-based approach has fewer limitations in increasing the slab size for SNR gain than MOTSA, and could generate stable vessel contrast even with limited arterial and/or venous flow potentially in the diseased leg. The scan time could be further reduced by a variable-density sampling version of 3D concentric cylinders trajectory [11] and/or using a sharper RF pulse profile.
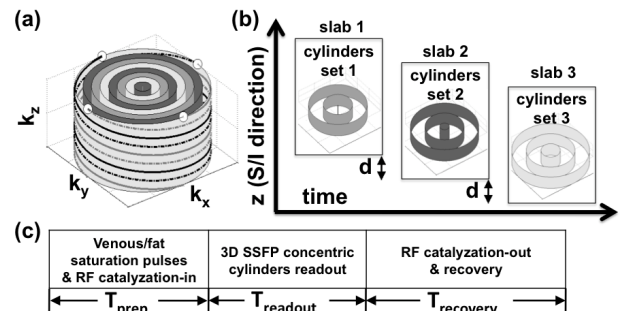
Fig. 1. (a) A 3D concentric cylinders k-space trajectory depicted with nine cylinders. (radius of the innermost cylinder = 0). Four helical interleaves are shown on the side of the outermost cylinder. **(b)** Data acquisition scheme of c-SLINKY. A subset of the cylinders are acquired at each slab, incremented by a distance d equal to the resolution in z. **(c)** Timing diagram for one segment of each slab.
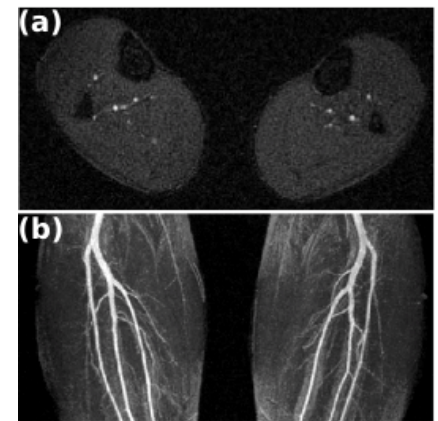
Fig. 2. (a) Axial slice (b) Coronal MIP image of the calf acquired from c-SLINKY.
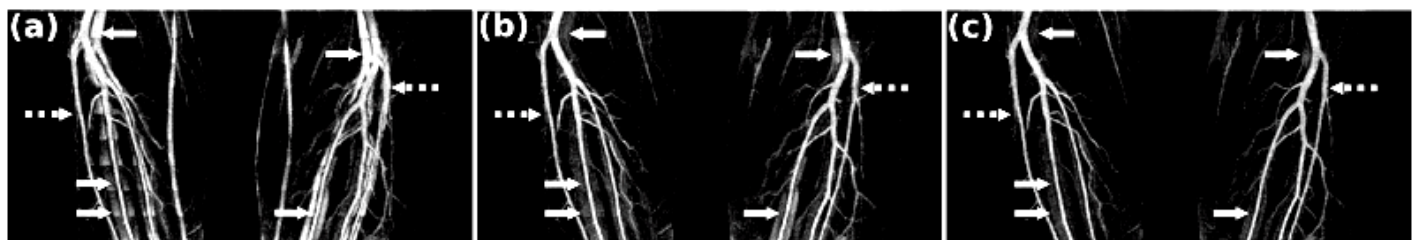
Fig. 3. Coronal MIP images of the calf: **(a)** MOTSA without venous saturation pulse **(b)** MOTSA with venous saturation pulse **(c)** c-SLINKY with venous saturation pulse. The same window/level was chosen to focus on the degree of venous suppressions. Solid arrows show relatively uniform venous suppressions in (c) compared to (a) and (b). Dotted arrows in (a) and (b) indicate venetian blind artifacts that disappear in (c).

References: [1] Wright, MRM 17:126, 1991. [2] Brittain, ISMRM, p.1710, 2003. [3] Stafford, MRM 59:430, 2008. [4] Liu, JMRI 8:903, 1998. [5] Liu, JMRI 8:912, 1998. [6] Kwon, ISMRM, p.1280, 2011. [7] Liu, MRI 17:689, 1999. [8] Dharmakumar, MRM 53:574, 2005. [9] Brittain, ISMRM, p.1913, 1999. [10] Parker, MRM 17:434, 1991. [11] Ruppert, ISMRM, p.2112, 2004.