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

Kie Taek Kwon¹, Holden H. Wu¹, Taehoon Shin¹, Adam B. Kerr¹, Dwight G. Nishimura¹, and Jean H. Brittain³

¹Electrical Engineering, Stanford University, Stanford, CA, United States; ²Cardiovascular Medicine, Stanford University, Stanford, CA, United States; ³MR Global Applied Science Laboratory, GE Healthcare, Madison, WI, United States

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) [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: SLINKY with 3D Concentric Cylinders (c-SLINKY): 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_s 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].

Pulse Sequence: Figure 1c shows the timing diagram, multiple segments of which are employed 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.

Imaging Parameters: 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 = 280×280×26.4 mm³ (matrix size = 256×256×24). 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_{recovery} = 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 with 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.