Peripheral MR Venography using Sliding Interleaved Cylinder (SLINCY) Imaging

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Purpose: MR venography is a promising alternative to the established sonography for the diagnosis and monitoring of venous disease in regions largely inaccessible to ultrasound. Among others, non-contrast-enhanced (NCE) approaches for MR venography based on SSFP sequences have been of interest [1-3] due to its superior capacity to generate high SNR and vascular contrast. Recently, a sliding interleaved cylinder (SLINCY) acquisition [4] based on a sliding interleaved ky (SLINKY) acquisition [5] was proposed for MR angiography targeting arteries. In this work, the SLINCY acquisition was incorporated into an NCE magnetization-prepared 3D SSFP sequence for MR venography in the lower extremities, which achieves artery-vein contrast by suppressing the arterial signal while retaining a venous flow-independent approach.

Methods: SLINCY: The SLINCY acquisition consists of a series of overlapped thin slabs for volumetric coverage. For each thin slab, one of N interleaved subsets of 3D concentric cylinders (Fig. 1a) is collected and the slab location is incremented by a distance equal to the resolution in the slab direction (Fig. 1b). After gridding, each slice is reconstructed by combining partial k-space data from the N consecutive slabs containing the slice in a hybrid space (z-k_x-k_y). Employing concentric cylinders instead of 3DFT sequence allows SLINCY to offer faster scan times and more distributed artifacts from k-space amplitude modulation while suppressing venetian blind artifacts similar to SLINKY.

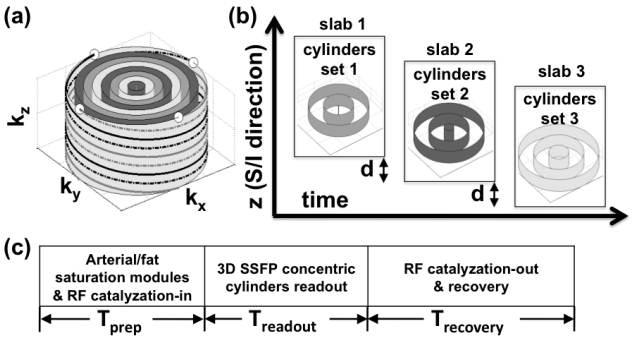

Fig. 1. **(a)** A 3D concentric cylinders k-space trajectory depicted with nine cylinders. Four helical readouts are shown on the outermost cylinder. **(b)** Data acquisition scheme of SLINCY. A subset of cylinders is collected at each slab in an interleaved way (N = 3), incremented by a distance d equal to the resolution in z between slabs. **(c)** Timing diagram of a magnetization-prepared 3D SSFP sequence for venography using SLINCY.

Pulse Sequence: Figure 1c shows the timing diagram of a magnetization-prepared 3D SSFP sequence for venography using SLINCY. For each slab, an interleaved subset of cylinders is collected in a centric-ordered and segmented way to capture the transient contrast from arterial and fat saturation modules. T_{prep} + $T_{recovery}$ is kept short (~500 ms) to yield sufficient blood-muscle contrast, and peripheral gating (PG) is used to capture the peak of arterial inflow.

Imaging Parameters: In vivo studies of thighs on four healthy volunteers were performed on a GE Excite 1.5 T scanner with an 8-channel cardiac coil. Gradients for the SSFP version of the SLINCY acquisition were designed to provide isotropic resolution = 1.4 mm and FOV = 340×340×42 mm^3 for each slab. TE/TR = 2.5/5.4 ms, and flip angle = 70°. k-Space of each slab was divided into two segments. In each segment, $T_{readout}$ = 400 ms (75 TRs), T_{prep} = 200 ms, and $T_{recovery}$ = 150~350 ms. The arterial saturation module presaturated a 130-mm-thick region that is 10 mm apart from each imaging slab. A total of 240 slabs were acquired to cover 30 cm in the S/I direction. Total scan time was 6~8 minutes. Images were reconstructed with 3D gridding followed by a SLINCY reconstruction (N = 24) and a maximum-intensity-projection (MIP) with a factor of two zero-padding. For comparison, images without flow saturation and with a venous saturation module (65-mm-thick, 5 mm apart) were acquired, which are subtracted from each other to produce a venous-only image.

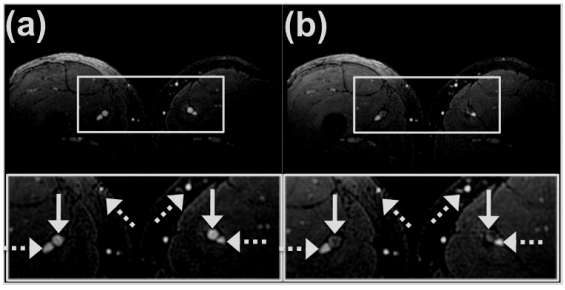

Fig. 2. A component axial slice of the thigh: **(a)** Without arterial saturation **(b)** With arterial saturation. (solid arrows: deep arteries, horizontal dashed arrows: deep veins, diagonal dashed arrows: superficial veins)

Results: Figure 2 demonstrates that the SLINCY acquisition is feasible without any observable artifacts in the component slice, and the arterial saturation module successfully suppresses the arterial signal (Fig. 2b). Compared to Fig. 3a without flow saturation, this approach (Fig. 3d) can depict the thigh with relatively uniform venous signal and arterial suppression throughout the FOV. Although background (muscle/fat) suppression is not as uniform as the subtractive method (Fig. 3c), this non-subtractive approach is less vulnerable to insufficient venous inflow (lower part of Fig. 3b) and requires only one acquisition.

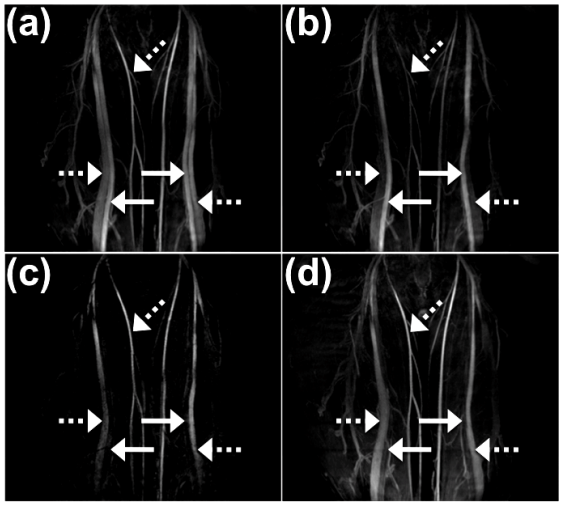

Fig. 3. Coronal targeted MIP images of the thigh: **(a)** Without flow saturation **(b)** With venous saturation **(c)** Difference between b and a **(d)** With arterial saturation. (solid arrows: deep arteries, horizontal dashed arrows: deep veins, diagonal dashed arrows: superficial veins)

Discussion and Conclusion: We demonstrated the feasibility of MR venography using SLINCY. This approach generates stable vessel contrast even with limited arterial and/or venous flow because it distributes the arterial-suppression effects evenly over the FOV and does not rely on venous inflow. In the future, we will exploit the thin-slab-scan nature of SLINCY to achieve better arterial and background suppressions by optimizing sequence parameters for each thin slab.

References: [1] Edelman et al., Radiology 2009;250:236. [2] Lindquist et al., AJR 2010;194:1357. [3] Priest et al., 19th ISMRM, p.1289, 2011. [4] Kwon et al., 20th ISMRM, p.3898, 2012. [5] Liu et al., JMRI 1998;8:903.