

# Bolus-tracking ASL using 3D center-out EPI trajectories in steady-state

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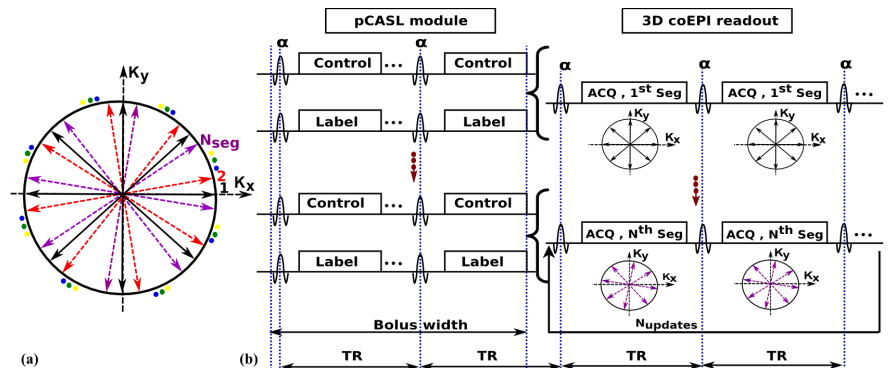
**Target audience.** Researchers interested in EPI, center-out readout strategies, and dynamic vascular and perfusion imaging.

**Purpose.** 2D EPI and EPSI modifications relying on center-out trajectories have been introduced recently.<sup>1,2</sup> Here, a 3D variant with cylindrical encoding<sup>3</sup> is combined with an arterial spin labeling (ASL) technique that created a well-defined bolus at the positions of large brain-feeding arteries. It is demonstrated that the ASL bolus can be tracked during the passage through the large vessel compartment of the brain by applying the 3D center-out EPI trajectories in steady-state. Goal was to obtain time-resolved, position-dependent ASL difference images from which information about dynamic features of the ASL bolus could be extracted.

**Methods.** Cylindrically-encoded 3D center-out EPI readout allowing image acquisition at very short echo time was described in previous work<sup>3</sup>. A modification is that the cylindrical  $k$ -space points were interpolated onto the Cartesian grid by using the conventional Kaiser-Bessel gridding method optimized with a minimal oversampling ratio<sup>4</sup>. Overly dense points near the  $k$ -space center were corrected by a density compensation function (DCF). The algorithm is based on the original work of O'Sullivan<sup>5</sup> with an in-house C++ implementation. In the current work, this readout is combined with a pCASL<sup>6</sup> labeling module (balanced gradients, Hanning-shaped RF pulses, duration 500  $\mu$ s, flip angle 22°, pulse interval 1400  $\mu$ s, total duration 444 ms) which will be referred to as 'ASL bolus'. The total  $k$ -space of 96 spokes was divided into 16 segments (6 spokes each). After an ASL bolus in either the control (C) or labeling (L) condition, the same segment (e.g., the first segment depicted as black arrows in Fig. 1a) is recorded a variable number of times in order to observe the passage of the bolus into the brain for a period of about 3 s. Imaging parameters were chosen in order to provide a sufficient penetration depth of the ASL bolus (slab-selective excitation along the readout or physical  $z$ -axis, excitation width 96 mm, flip angle 6°) and a sufficient signal intensity (TE 1.2 ms). By acquiring only 32 readout points (BW 3256 Hz/pixel, FOV 96 mm) for each of a total of 32 phase-encoding steps, a correspondingly short TR of 37 ms (including the duration of a non-selective fat-saturation module preceding each slab selection) was achieved. Time-resolved data of all segments were acquired subsequently with preceding ASL boluses in the C and L conditions (Fig. 1b). It should be noted that no temporal gap was introduced during the overall course of acquisition. The steady state created in the imaging volume by the repeated slab selective excitation was maintained between the acquisitions of subsequent segments by short interrupts within each ASL bolus during which slab-selective excitation pulses were played out (Fig. 1b). Thereby, no preparing pulses were required to drive the imaging slab back to steady state. Finally, all segments of total  $k$ -space of either the C or L condition belonging to the same time after ASL bolus termination were combined and reconstructed. The time resolution of the bolus tracking ASL method is given by the total number of spokes (96) divided by the number of acquired segments (16) multiplied by TR (37 ms), that is 222 ms.

**Results & Discussion.** Figure 2A demonstrates the quality of the reconstructed 3D images in the time series acquired in either the C or L condition. Their difference images are characterized by the anatomical features of large brain-feeding arteries as, for example, visible in the difference image acquired 666 ms after termination of the ASL bolus (Fig. 2B). Full ASL bolus curves taken from two positions along a branch of the anterior cerebral artery (ACA, arrows in Fig. 2B) are also shown in Fig. 2. As expected, the ASL bolus measured at the more downstream position (red) has a lower signal maximum, is appearing delayed (by about 450 ms), and is showing a slightly broader response. The goal of future work will be to extract quantities related to the arterial transit time (shift), the dispersion of transit times (width) and the blood volume of the large vessel compartment (total signal intensity).

**References.** [1] S. Hetzer, *Magn. Reson. Med.* 65:165-175 (2011). [2] C. Labadie, *Magn. Reson. Med.* 70:16-24 (2013). [3] M. Shrestha, *Proc. ISMRM* 21:2367 (2013). [4] P.J. Beatty, *IEEE Trans. Med. Imaging* 24: 799-808 (2005). [5] J.D. O'Sullivan, *IEEE Trans. Med. Imaging* 4: 200-207 (1985). [6] D. Weiying, *Magn. Reson. Med.* 60: 1488-1497 (2008).



**Fig. 1. (a)** Different colors denote spokes from different segments of  $k$ -space **(b)** Schematic of the ASL bolus tracking method with segmented acquisitions during C and L conditions.

**Fig. 2.** Time-resolved difference signal of C and L conditions in two positions inside the ACA. Frames were recorded after ASL bolus termination with temporal resolution 222 ms. Inserts show **(A)** an image example recorded during L condition, and **(B)** the difference image of C and L conditions, 666 ms after ASL bolus termination.

