Guiding Off-Resonance Interventional MR with Dephased Fast Low-Angle Positive-Contrast Steady-State Free Precession Imaging

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Introduction: Off-resonance positive contrast imaging (PCI) methods that allow for the visualization of off-resonant spins as bright regions within images have been reported [1-5]. One such method, Fast Low-Angle Positive-contrast Steady-state free precession (FLAPS) imaging [6], has been proposed as a time-efficient PCI method that utilizes low imaging flip angles. FLAPS technique takes advantage of the unique spectral response of the steady-state free precession (SSFP) signal with respect to flip angle to generate signal enhancement from off-resonant spins while minimizing the signal from on-resonant spins. However, when FLAPS is used for thick-slice projection imaging, positive contrast is hindered by partial volume averaging effects that reduce the conspicuity of the positive contrast. In this work, we propose a modified technique, dephased FLAPS (dFLAPS) imaging, that extends the capabilities of FLAPS imaging into thick-slice positive contrast imaging. To demonstrate the effectiveness of the dFLAPS method over the conventional FLAPS method, the dFLAPS approach is compared to the conventional FLAPS method for visualization of mildly magnetic-susceptibility-shifted interventional devices over thick imaging slices.

Methods: The dFLAPS method works by dephasing the on-resonant spins (background) in the slice-select direction, permitting selective visualization of the signals from the off-resonant spins during FLAPS imaging. The dFLAPS sequence is shown in Figure 1. The dFLAPS technique was tested on a whole-body 1.5T scanner (Siemens, Germany) for thick-slice imaging of three interventional devices: (1) a 0.018 inch radiopaque coronary guidewire (Terumo Medical Corporation, Tokyo), (2) biopsy needle (18 gauge × 15 cm, E-Z EM Inc.,USA), and (3) a coronary stent (diameter/length = 4.5/40 mm, Boston Scientific,USA). Imaging of the guidewire, needle, and stent was performed in a thoracic aortic phantom filled with blood (Elastrat, Geneva), *ex-vivo* liver tissue, and in a blood bath, respectively. In order to evaluate the dFLAPS results, conventional FLAPS imaging was also performed. Imaging parameters during MRI of the guidewire were: field-of-view (FOV) = 22.5×30 cm^2, matrix = 144×192, repetition/echo time (T_R/T_E) = 2.8/1.4 ms, flip angle (α) = 10°, slice thickness (SL_{TH}) = 50 mm, acquisition time (TA) = 0.4 s. Imaging parameters during MRI of the biopsy needle were: FOV = 30×30 cm^2, matrix = 128×128, T_R/T_E = 2.5/1.2 ms, α = 5°, SL_{TH} = 25 mm, TA = 0.3 s. Imaging parameters during MRI of the coronary stent were: FOV = 30×30 cm^2, matrix = 256×256, T_R/T_E = 3.6/1.8 ms, α = 10°, SL_{TH} = 50 mm, TA = 0.9 s. Note that all scan parameters used for FLAPS and dFLAPS acquisitions were the same, except, that dFLAPS scans employed a phase dispersion of 2π radians through the slice. For both the dFLAPS and FLAPS images, the contrast values between the signal-enhanced regions (due to the interventional devices) and background were calculated by the relation $(S_d-S_b)/S_b$ where S_d and S_b denote the device and background signals, respectively.

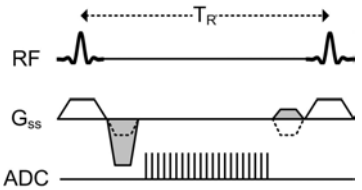

Figure 1. Single repetition time (T_R) within the dFLAPS sequence. An extra slice-select gradient (G_{SS}) area is applied before data acquisition (ADC) to impart dephasing through the slice thickness. Following the ADC, an equivalent gradient area of opposite polarity is applied to ensure balanced gradient structure over the T_R. Dashed lines on the G_{SS} axis denote typical gradient values for conventional SSFP-based FLAPS imaging.

Results & Discussion: Images acquired with FLAPS and dFLAPS techniques for visualizing a guidewire, a needle, and a stent are shown in Figures 2, 3, and 4, respectively. Contrast values (mean ± standard deviation) measured at the tip, medial, and distal portions of the coronary guidewire with dFLAPS(FLAPS) were 15.0±5.0(-0.2±0.03), 67.0±1.8(4.3±0.1), 224.3±1.8(15±0.5). Contrast values for the biopsy needle and the stent with dFLAPS(FLAPS) were 20.8±1.9(0.1±0.1) and 35.9±2.2(0.1±0.3), respectively. Compared to FLAPS, dFLAPS provided significantly improved suppression of background signal with bright depiction of the interventional device ($p < 0.001$).

Conclusion: Dephased FLAPS (dFLAPS) offers better contrast than conventional FLAPS for thick-slab (i.e. projection) visualization of susceptibility-shifted interventional devices. dFLAPS appears to be a promising technique for visualization of interventional devices with positive contrast and, given its fast and low flip angle acquisition capabilities, may lend itself to real-time tracking of interventional devices.

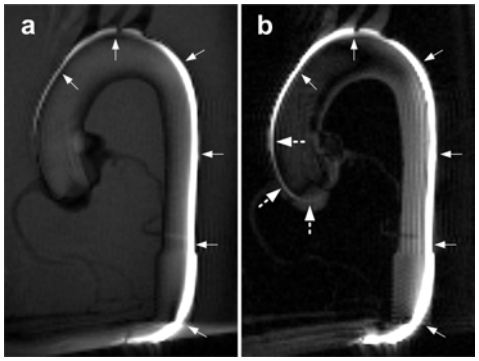

Figure 3. Radiopaque 0.018 inch coronary guidewire inserted into a thoracic aortic phantom filled with blood: **(a)** image acquired with conventional FLAPS; **(b)** image acquired with dFLAPS. Note the improved visualization of the guidewire with dFLAPS, especially at its tip (dashed arrows).

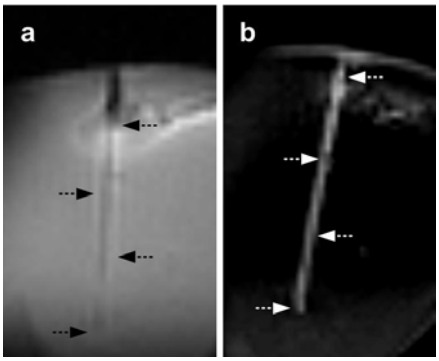

Figure 2. Biopsy needle inserted into *ex-vivo* liver tissue: **(a)** image acquired with conventional FLAPS; **(b)** image acquired with dFLAPS. Note the suppression of background and the improved visualization of the needle with dFLAPS.

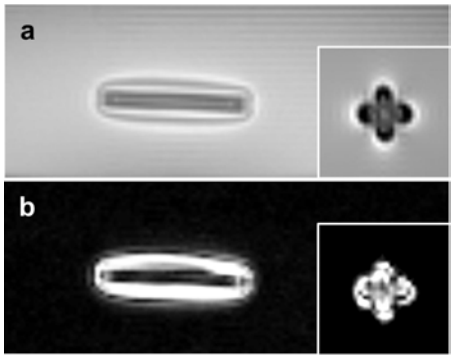

Figure 4. Coronary stent placed in a blood bath: **(a)** image acquired with conventional FLAPS; **(b)** image acquired with dFLAPS. Insets depict short axis images through the stent. Note the improved visualization of the stent with dFLAPS.

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