Dephased FLAPS MRI for Real-Time Guided Biopsy: Feasibility and Accuracy Study in *Ex-Vivo* Liver Tissue

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Introduction: MRI methods exploiting magnetic susceptibility effects have been proposed for visualizing and tracking interventional devices with negative image contrast [1,2]. These methods, however, produce weak negative image contrast when thick imaging slices are used [3]. Recently, MRI methods that enable the visualization of off-resonant spins near susceptibility-shifted interventional devices as bright regions (i.e. with "positive contrast") have been reported [3-5]. These positive contrast methods may allow for improved visualization of susceptibility-shifted interventional devices relative to negative contrast methods. One such method, Fast Low-Angle Positive-contrast Steady-state free precession (FLAPS) imaging, has recently been proposed as a fast acquisition scheme that permits real-time imaging [6]. The 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 suppressing the signal from on-resonant spins at relatively low flip angles. Positive contrast with FLAPS imaging, however, is reduced with projection-based (i.e. thick-slice) acquisitions due to partial volume averaging effects. To overcome this limitation, dephased FLAPS (dFLAPS) – a technique employing dephasing gradients to suppress background signal while uncovering the desired SSFP-based FLAPS contrast – has been developed. It is envisioned that dFLAPS may be of use during real-time MRI-guided needle biopsy. The purpose of this study was to evaluate the feasibility and accuracy of dFLAPS for guiding a biopsy needle to a pre-defined target within *ex-vivo* liver tissue.

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. MR imaging was performed on a 1.5 T whole-body clinical scanner (Sonata; Siemens, Germany). A cylindrical titanium target (diameter/length = 1.5/4 mm) was introduced into a three-pound slab of *ex-vivo* beef liver. The *ex-vivo* liver was immersed in a saline bath and placed in the MRI scanner. A head coil was used for image reception. After SSFP scout scans were performed to locate the titanium target, two orthogonal 25-mm-thick dFLAPS imaging slices, intersecting at the location of the target (Figure 2), were prescribed and repetitively acquired in an interleaved manner. Under continuous dFLAPS imaging of these two slices, a MRI-compatible biopsy needle (22 gauge × 15 cm; EZ Em Inc., USA) was introduced and advanced towards the target under real-time MRI guidance. A single pass was made to reach the target. Imaging parameters for the dFLAPS sequence were: repetition/echo time = 3.22/1.61 ms, field-of-view = 20 × 20 cm^2, matrix = 128 × 128 (resulting in an in-plane spatial resolution of 1.6 × 1.6 mm^2), slice thickness = 25 mm, acquisition time per slice = 0.41s (frame rate = 2.4 Hz), radians of dephasing throughout the thickness of the slice = 2π [7]. In order to validate the MR confirmation of the biopsy needle reaching the titanium target, the *ex-vivo* liver phantom was transferred to a C-Arm system (PowerMobile; Siemens, Germany) and x-ray images were obtained. Three orthogonal projections (Figure 2) were acquired in order to calculate orthogonal deviations (needle tip to the center of the target) in 3D space. This study (MR-guided targeting and x-ray validation) was repeated 15 times in order to evaluate the reproducibility of the technique.

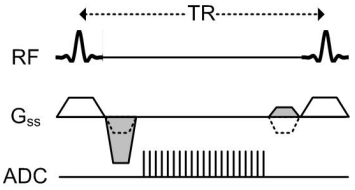

Figure 1. Single repetition time (T_R) within the dFLAPS sequence. Before data acquisition (ADC), additional slice-select gradient (G_{SS}) area is applied to impart spin dephasing through the slice. Equivalent gradient area of the opposite polarity is applied after the ADC to ensure a balanced G_{SS} zeroth-moment over the T_R. Dashed lines on the G_{SS} axis denote gradient values for conventional SSFP-based FLAPS imaging.

Results & Discussion: Based on the gold-standard x-ray measurements, mean distance between the needle tip to target center was 4.76 ± 1.59 mm (range = 2.14-7.6 mm). Mean tip-to-target deviations in the three orthogonal directions were 2.81 ± 1.17, 2.99 ± 1.36, and 2.03 ± 1.09 mm, respectively. Considering the physical size of the target and device, the enlarged appearance of them mediated by the off-resonance fields, and the in-plane spatial resolution of acquired MR images (1.6 × 1.6 mm^2), tip-to-target deviations were fairly small. Mean time required under MR guidance to place the needle tip at the location of the target was 99.0 ± 34.9 s (range = 55.8-132.8 s). In some instances, the elasticity of the tissue altered the location of the needle tip after initial placement, requiring slight adjustment of the needle (under MR guidance) prior to x-ray imaging. In practice, a MR image displaying an anatomical target (e.g. a tumor), rather than an artificial target (as used here), could be superimposed onto the dFLAPS images at run-time.

Conclusion: Dephased Fast Low-Angle Positive-contrast Steady-state free precession (dFLAPS) imaging allows for accurate real-time MRI guidance of a biopsy needle into liver tissue *ex-vivo*, and provides clear depiction of the needle relative to background despite the use of thick imaging slices.

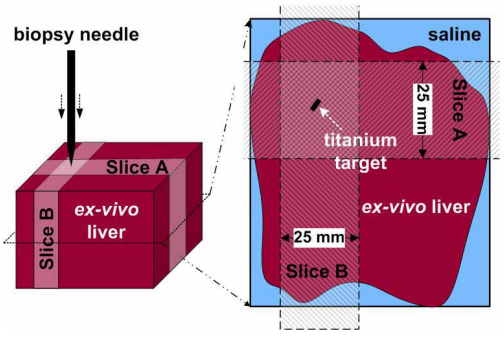

Figure 2. A schematic illustration of the two orthogonal thick slices (slices A and B) acquired with dFLAPS through the *ex-vivo* liver tissue and the position of the titanium target.

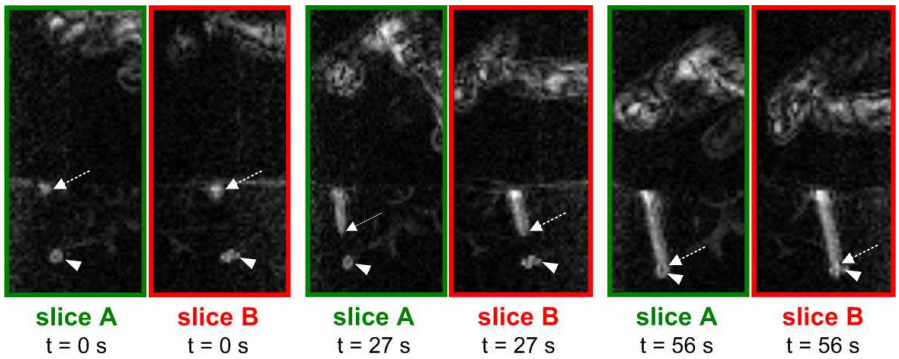

Figure 3. Select frames displaying the manual guidance of the biopsy needle (arrows) to the target (arrowheads) under real-time dFLAPS imaging. The needle is clearly visible relative to background tissue. The leftmost images depict the needle entering the tissue, while the rightmost images display the needle tip in close proximity to the target. The operator's hand is visible at the top of the images.

References: **[1]** Bakker et al. Radiology. 1997;202:273 **[2]** Peeters et al. Phys Med Biol. 2006;51:N127 **[3]** Seppenwoolde et al. MRM. 2003;50:784 **[4]** Kraitchman et al. ISMRM 2005. p. 2165 **[5]** Bakker et al. MRM. 2006;55:92 **[6]** Dharmakumar et al. Phys Med Biol. 2006;51:4201 **[7]** Dixon et al. MRM. 1986;3:454