The Utility of Sweep Imaging with Fourier Transform (SWIFT) in breast cancer.

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Introduction: Dynamic contrast enhanced (DCE) MRI has emerged as a useful adjunct technology in the staging of high risk screening patients and in staging of known breast cancers. While the sensitivity of DCE MRI in detecting breast cancer can approach 100% and imaging of dense breast is far better than mammography, DCE MRI currently lacks the required specificity to be used as a general screening modality [1].

SWeep Imaging with Fourier Transform (SWIFT) is an emerging MRI method utilizing nearly simultaneous radio frequency sweep excitation and signal acquisition [2, 3]. It has many unique properties compared to more familiar sequences, such as nearly zero excitation to acquisition delay, relative insensitivity to motion, amenability to motion correction (due to center out radial k-space scanning), and quiet operation. Importantly, the same SWIFT data can be formatted after acquisition into both high spatial resolution morphological images, and high temporal resolution DCE images. This reduces time in magnet and thus has potential to reduce the cost of breast MRI. Scanning. In this work, the feasibility of SWIFT for DCE and morphological imaging of breast patients is reported.

Table 1: Pilot SWIFT Breast MRI Protocol

2 min	shimming, pre-scan, scout
1-2 min	Flash images for comparison FS, no FS
(4 min)	(Optional) T_2 weighted standard FS SEMS
(4 min)	(Optional) High Resolution standard FS Flash
20 sec	SWIFT pre-scans, phase reference and gain
1-2 min	SWIFT FOV check, FS
2-4 min	Double Angle Method GRE B_1 map
2-4 min	SWIFT Variable Flip Angle T_1 map
2-6 min	SWIFT DCE FS, pre-contrast injection (Magnavist™ 0.1 mM/kg at 2 cc/s)
6-12 min	SWIFT DCE FS, post-contrast
	(optional) further SWIFT test scans

16.33 min Minimum with current T_1 and B_1 mapping

Methods: Six patients with breast pathology (BI-RADS scores of 4-5) who underwent SWIFT DCE MRI prior to biopsy after mammograms. Studies were conducted with IRB approval. The MRI protocol is summarized in Table 1. In all cases, 62.5 kHz 3D SWIFT acquisition was utilized with isotropic Halton view ordering [4, 5]. A full non-overlapping spherical region of k-space was acquired once every 3 seconds. A 6 minute scan consists of 128 such segments, and can be repeated with further non-overlapping views. CHESS fat suppression consisting of a 4 ms Gaussian pulse bracketed by pairs of 8 ms ramped spoilers (except in the case of the silicone implant patient, which was a 10 ms HS4 pulse covering fat and silicone peaks) was interleaved every 8 SWIFT views. TR was 4.4 ms in all cases. Initial studies used a symmetric gapped HS1R256 pulse [2, 3] for SWIFT yielding a k-space radius of 128 complex points after processing while the latest study utilized HS2R128 followed by 128 points of pulse-free acquisition for a total of 196 usable complex points after correlation post processing [2, 3]. SWIFT requires fast transmit and receive switching, and low proton background signal from the coil. Two different sized modified single breast SWIFT compatible coils were used with surface quadrature transmit and two-channel receive. The coil was matched to patient breast size. Initial SWIFT DCE images at 6 sec. time resolution 128^3 spatial matrix as well as morphological 256^3 matrix were reconstructed from the same scan data. Subsequently this was increased to 192^3 and 384^3 for the latest patients, yielding 0.8 mm or better isotropic resolution.

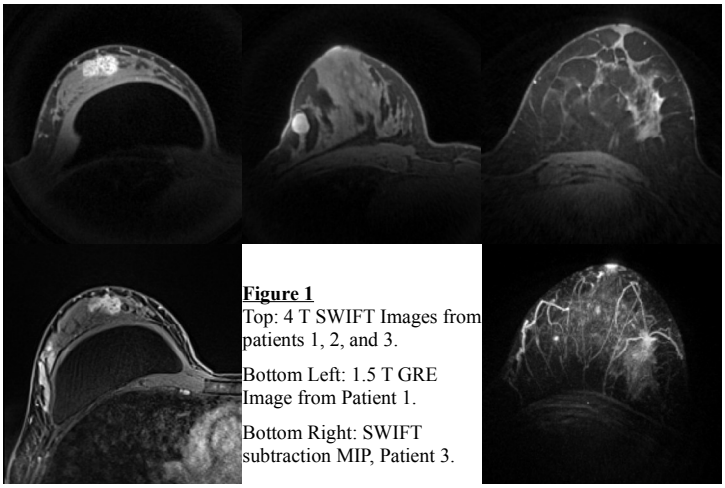

Figure 1
Top: 4 T SWIFT Images from patients 1, 2, and 3.

Bottom Left: 1.5 T GRE Image from Patient 1.

Bottom Right: SWIFT subtraction MIP, Patient 3.

Results: The first presented patient is a 44-year-old, previously healthy woman, with breast implants and a palpable mass in her right breast, which proved to be mass-like DCIS. She underwent a DCE MRI, which revealed the 1.6 cm x 2.3 cm mass, as well as an area of lateral enhancement 4.0 cm in length. This lateral area was determined to by benign fibrocystic changes. The DCIS and lateral enhancement were seen on SWIFT as a 1.5 cm x 2.2 cm enhancing mass at the 12 o'clock position and 3.6 cm area of non-mass like enhancement respectively.

The second patient is a 31-year-old woman who presented to her physician with a painful lump. Ultrasound revealed a 1.6 cm mass consistent with a fibroadenoma and diagnostic mammogram had a corresponding density as well. SWIFT revealed a well circumscribed and homogeneous 1.5 cm x 1.6 cm area of mass like enhancement at the 9 0'clock position in the right breast. Pathology determined the mass was a fibroadenoma without evidence of atypia.

The final patient shown is a 53-year-old woman who presented with a 5 mm spiculated mass with ill-defined borders on screening mammogram and a 1-year history of brownish discharge. The discharge was worked up 6 months prior to presentation, and was consistent with duct ectasia. Biopsy of the mass revealed grade 2 infiltrating ductal cancer. Her SWIFT MRI revealed a 5 mm x 3 mm irregular area of mass like enhancement at the 1:30 position, 5.5 cm from the nipple.

Discussion: SWIFT imaging of breast lesions show both benign and malignant features similar to clinical DCE breast MRI. SWIFT is a quiet and fast imaging modality, completed in 3-6 minutes pre and post-contrast, with excellent temporal and spatial resolution, and reduced motion artifacts. SWIFT is amenable to quantitative pharmacokinetic modeling (in-progress) and may allow more accurate K_{trans} measurements due to the reduced T_2^* effects and high temporal resolution [6]. The breast SWIFT sequence is 45 dB quieter that the corresponding fat suppressed T_1 weighted 3D FLASH sequence used at 4 T previously for research breast DCE imaging. There is the potential for significant in magnet time savings due to variable time/resolution format reconstructions. Further evaluation is necessary with dual breast coils, better axillary coverage, and additional patients (all also in-progress).

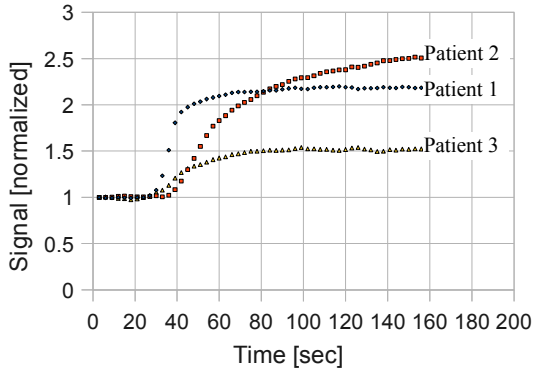

Figure 2: SWIFT DCE time-courses in the lesion ROI, 6 sec. resolution.

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