Three-dimensional first-pass cardiac perfusion MRI using a stack-of-spirals aquisition

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Introduction: Three-dimensional first-pass myocardial perfusion imaging (MPI) has shown great promise for the precise sizing of defects, for providing high perfusion contrast, and for correction of respiratory drift [1-3]. However, 3D MPI remains an experimental approach primarily due to the need for large dimensional encoding which for traditional 3DFT imaging, requires either impractical acceleration factors, or sacrifices in spatial resolution. The goal of this study was to develop a high-resolution whole-heart 3D MPI method using a stack-of-spirals acquisition accelerated by *k-t* SENSE. The developed method was tested at rest in cardiac patients and compared with standard 2DFT perfusion imaging.

Methods: Pulse sequence: The pulse sequence consisted of two saturation recovery acquisition modules for consecutive 3D spiral and single-slice 2DFT perfusion imaging during each R-R interval (Fig. 1). The 3D spiral acquisition was synchronized to the stable diastolic phase by detecting the R wave at every TR of the 2DFT acquisition and adjusting the subsequent delay to the next spiral acquisition module (denoted by TD in Fig. 1).

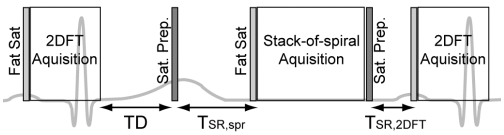

Figure 1. Timing schematic of simultaneous 3D spiral and 2DFT perfusion imaging.

Spiral undersampling and reconstruction: A set of ten dual-density spiral trajectories was designed and two interleaves out of the ten were acquired per each k_z encode such that inner *k*-space was fully sampled and outer *k*-space was 5-fold undersampled. The acquired spiral interleaves were rotated by two interleaves (72 º) in the k_z direction, and were rotated by four interleaves (144 º) over cardiac cycles (Fig. 2a), which yielded the largest distances between the mainlobe and side-lobes of the corresponding point spread function (Fig. 2b). Non-Cartesian *k-t* SENSE reconstruction with linear off-resonance correction was performed by solving pre-conditioned system equation iteratively using the conjugate gradient method [4].

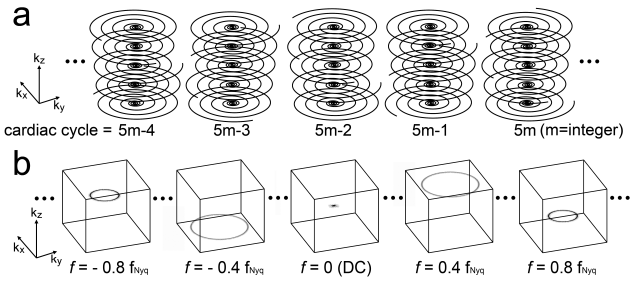

Figure 2. (a): Undersampling scheme of stack-of-spirals acquisition in *kx-ky-kz-t* domain shown at 5 consecutive cardiac cycles. (b): Resultant point spread function in *x-y-z-f* domain shown at 5 non-zero temporal frequencies (DC, $\pm 0.4\, f_{Nyq}$, $\pm 0.8\, f_{Nyq}$).

In-vivo experiments: Perfusion scans were performed using a GE 1.5 T scanner, an 8-channel cardiac array coil, and 0.1 mmol/kg gadolinium in 7 patients with suspected CAD under resting conditions. The 3D spiral parameters were spatial resolution = 2.4×2.4×9 mm^3, FOV = 38×38×9 cm^3, 10 section slices (after discarding 2 edge slices), TR = 9.8 ms, spiral readout time = 7.1 ms, readout bandwidth = 125 kHz, acquisition window = 230 ms, and number of acquired cardiac cycles = 40. $T_{SR,spr}$ = 140 ms and FA = 17° were chosen to minimize magnetization variation during the transient data acquisition [5]. The 2DFT parameters were $T_{SR,2DFT}$ = 40 ms, FA = 12°, spatial resolution = 2.4×2.4 mm^2, FOV = 33×33 cm^2, slice thickness = 9 mm, TR = 2.8 ms, readout bandwidth = 62.5 kHz, Cartesian 3-fold *k-t* SENSE acceleration [6] and acquisition window = 157 ms.

Results: Figure 3 shows representative 3D spiral and 2DFT images from a patient without perfusion defects. The 2DFT images and the corresponding center slice of the 3D data (dotted rectangle) exhibit nearly the same contrast uptake and wash-out, validated by time-intensity curves (TICs) shown in Fig. 4. Correlation coefficients between paired TICs across 42 myocardial segments in 7 subjects were significantly high (mean=0.96, standard deviation=0.05). The TIC upslope values of the two data sets show significant linear correlation with a linear fit slope of 1.21 (P<0.001) (Fig. 5). Peak SNR and CNR were 68.3±22.1 and 22.0±8.3 for 3D spiral perfusion, and were 35.0±9.8 and 15.8±5.5 for 2DFT perfusion.

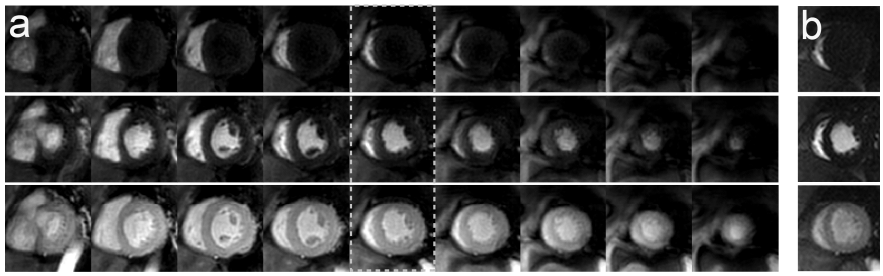

Figure 3. (a): 3D spiral perfusion images and (b): single-slice 2DFT perfusion images at the center slice of the 3D images (dotted box). Images at peak RV enhancement, peak LV enhancement, and peak myocardial enhancement are shown from the top, middle, and bottom rows, respectively.

Discussion: High-quality whole-heart perfusion imaging is possible with an accelerated 3D spiral acquisition. Spatial resolution and image quality are equivalent to those of 2DFT acquisition. Our next planned step is to utilize this approach during adenosine stress testing for sizing of stress-induced perfusion defects.

References: [1] P Kellman et al., ISMRM 2004: 310. [2] T Shin et al., JCMR 10:57, 2008. [3] V Vitanis et al., MRM 65: 575-587, 2011. [4] MS Hansen et al., MRM 55: 85-91, 2006. [5] M Salerno et al., MRM 65: 1602-1610, 2011. [6] J Tsao et al., MRM 50: 1031-1042, 2003.

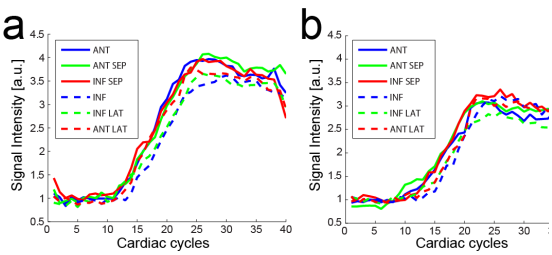

Figure 4. Normalized time-intensity curves for the center slice of 3D spiral (a) and 2DFT acquisition (b).

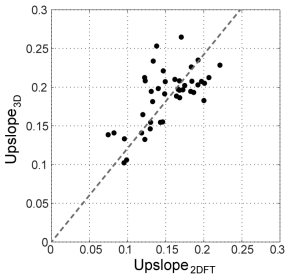

Figure 5. Time-intensity curve upslopes of 2DFT vs 3D spiral perfusion.