HIGH SPATIO-TEMPORAL FIDELITY NONGATED CARDIAC MRI WITH A 3 SECOND PATIENT-ADAPTIVE SCAN

B. SHARIF[1], J. A. DERBYSHIRE[2], AND Y. BRESLER[1]

[1]ELECTRICAL AND COMPUTER ENGINEERING, COORDINATED SCIENCE LABORATORY, UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN, URBANA, IL, UNITED STATES, [2]TRANSLATIONAL MEDICINE BRANCH, NHLBI, NATIONAL INSTITUTES OF HEALTH, BETHESDA, MD, UNITED STATES

INTRODUCTION Dynamic imaging of the human heart without explicit cardiac synchronization promises to extend the applicability of cardiac MRI (CMRI) to a larger patient population and potentially expand its diagnostic capabilities. However, conventional cardiac MR with no ECG gating typically suffers from low image quality or inadequate spatio-temporal (S-T) resolution and fidelity. Patient-Adaptive Reconstruction and Acquisition in Dynamic Imaging with Sensitivity Encoding (PARADISE) [1-3] is a highly-accelerated non-gated imaging method that enables artifact-free imaging with high S-T resolutions by utilizing novel computational techniques to optimize the imaging process. The proposed method is doubly adaptive as it adapts both the k-t data acquisition (k=spatial frequency, t=time) and reconstruction schemes. In addition to using parallel imaging, the method gains acceleration from a *physiologically-driven* S-T support model in the *y-f* space [4] (also called the *x-f* space [5]); hence, it is doubly accelerated. Recently [3,6], we have demonstrated the effectiveness of the PARADISE method for high resolution non-gated CMRI. The aim of the present work is to study the feasibility of high-resolution adaptive CMRI with short scans (~3 seconds/slice; 2D+t imaging) using PARADISE. We present a method enabling such short PARADISE scans by prospective (prior to the MR scan) adjustments to the *y-f* support model. Results of in-vivo experiments with high acceleration (R=7) and discussion of associated trade-offs are provided.

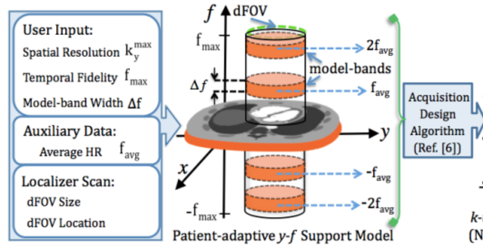


FIG. 1

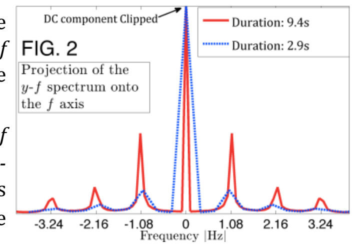
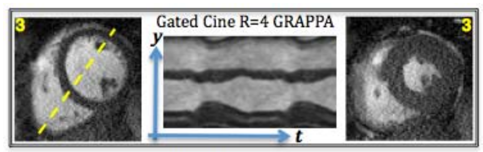


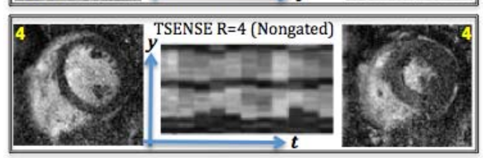
FIG. 2

THEORY The *Adaptive x-y-f Support Model* [4], characterizes the imaged slice by its *x-y-f* support, i.e., locations in *x-y-f* space where it has nonnegligible energy (Fig. 1). It captures the *approximate* periodicity of cardiac motion (by the *model-band thickness* Δf>0) and the localized dynamic FOV (dFOV). Further, the model parameters differ among subjects depending on average heart rate (HR) (f_{avg}), HR variability (Δf), and heart position (dFOV). These parameters are estimated prior to the scan (Fig. 1) [3].

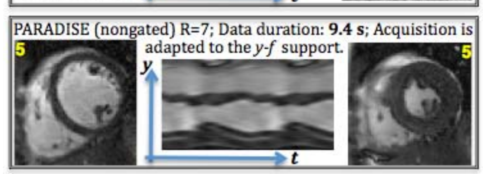
Design of the k-t Acquisition Schedule [1, 3, 6]. The acquisition design algorithm (Fig. 1) adapts the sample locations in k-t space based on the support model. The degrees of freedom in designing the k-t lattice [4,5] are: (1) Repetition time (TR) (2) Phase-encode (PE) step size (3) PE ordering (scrambled as in Fig. 1). A key feature is that, by solving a geometric optimization problem [6], all degrees of freedom are exploited so that high image quality is guaranteed. Specifically, a measure of the *y-f*-space g-factor is minimized [6].

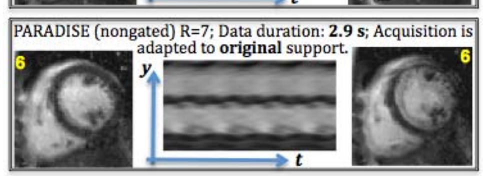
Prospective Accommodation of Short Scan Time: This is achieved by allocating thicker model-bands (increased Δf). Fig. 2 demonstrates the effect of shorter scan times on the underlying support sparsity. A 1-D frequency profile (projection) of a short-axis 2D+t cardiac-torso phantom [1] is shown with two different cine durations. Because of the finite time window, even in the exactly periodic case the harmonics have finite, non-zero bandwidth. As seen in Fig. 2, capturing most of the y-f-space energy (needed for high S-T fidelity) with shorter scan times requires thicker bands (higher Δf).

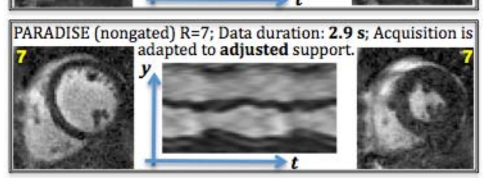




METHODS MR imaging was performed using a 1.5T Siemens Avanto scanner (Siemens Medical Solutions) with a 15-element cardiac-torso receiver array. Imaging with informed consent was performed under the NHLBI IRB. Data was collected for a healthy volunteer during a single breath-hold. Initially, a retrospectively gated segmented SSFP cine was acquired (256×208 matrix, 32 phases, temporal resolution=13.6ms, vps=4, R=4 GRAPPA, FOV=300×243mm, scan time=20s). The remaining experiments were performed without ECG gating. The *y-f* support parameters for the PARADISE scan were computed as follows: (1) Subject's average HR during the gated scan was used as an estimate for f_{avg} (=1.17Hz; actual scan HR: 63-74 bpm) (2) Heart position was estimated from localizer scans (|dFOV|=0.4×|FOV|) (3) Total of 9 harmonic bands were modeled to have a width of $\Delta f = f_{avg}/6$. Next, the acquisition design algorithm [6] was run to find the optimal k-t lattice (Fig. 1) resulting in acceleration rate of R=7 (TR=3.06ms). The designed sampling schedule was fed to a customized SSFP pulse sequence (192×192 matrix; TR=3.06ms; scan time=17.6s). Finally, a rate R=4 TSENSE acquisitions (192×207 matrix; TR=3.37ms; scan time=17.4s) was performed [7].







RESULTS & DISCUSSION Figs 3-4 show the results for the gated cine and TSENSE scans: reconstructed end diastolic/systolic frames and temporal changes for a 1D cut (along the dashed line in Fig 3) over 2 heartbeats—called a "y-t profile", as a visualization of temporal fidelity. Figs 5-7 show corresponding results for the PARADISE scan wherein the k-t data set is truncated to: (i) 9.4 seconds (Fig 5); (ii) 2.9 seconds (Figs 6-7). Using gated cine results (Fig 3) as a reference for nongated scans, PARADISE images in Fig 5 (9.4 s data) are visually artifact-free, whereas the PARADISE reconstruction in Fig 7 (same y-f support model but 2.4 s data) exhibits very poor fidelity and various artifacts (as expected). In contrast to Fig 6, in Fig 7 an "adjusted" y-f support is used with *model-bands twice as thick* ($\Delta f = f_{avg}/3$). This reduces the support sparsity causing some loss of SNR (higher g-factor) [6] but in exchange substantially increases temporal fidelity, which, in particular, is significantly higher than the TSENSE result (compare y-t profiles in Figs 4 and 7). This is because the temporal resolution of TSENSE (=174 ms) is insufficient to capture the true heart dynamics. Although the equivalent "minimum scan time" for TSENSE can be as lows as 1 heartbeat (≈0.9 s), the TSENSE method does not allow flexible trade-off of scan time for higher spatio-temporal fidelity. To this end, we presented a modification of PARADISE that enables high fidelity *nongated* cine imaging with very short scan times (≈3 s for 2D imaging). Such fidelity improvements are potentially significant for several CMRI applications including accurate imaging of wall-motion or valve cusps (with minimal breathholds) and interventional imaging.

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