

Contrast-enhanced free-breathing perfusion weighted MR imaging of the whole-liver with high spatial and temporal resolution.

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Purpose: Dynamic contrast-enhanced (DCE) imaging of the liver with high temporal resolution is a method of measuring perfusional changes in the liver and in focal liver lesions. Several studies have shown the utility of perfusion metrics in diagnosis of advanced liver fibrosis, and for characterization of angiogenic activity of hepatocellular carcinoma and liver metastases, as well as for monitoring antiangiogenic treatment response (1-3). 2D or 3D interpolated spoiled gradient-echo sequences are routinely used for liver perfusion imaging (PWI). Compared to 2D, 3D acquisitions have the advantage of covering the entire liver, which is essential when evaluating patients with multiple liver lesions, and in liver fibrosis and cirrhosis, where there is a heterogeneous distribution of the disease. However, this extended anatomic coverage is at the expense of lower temporal resolution and/or lower in-plane spatial resolution. Furthermore, prior to performing DCE analysis coregistration of dynamic volumes, which can be cumbersome and technically challenging, is essential to compensate for respiratory motion. For PWI to gain acceptance in routine clinical practice, acquisition schemes need to be robust to respiratory motion, and should be able to acquire simultaneous high spatial and temporal resolution T1-weighted dynamic data with whole-liver coverage. One approach for accelerated imaging acquisition is the use of compressed sensing (CS) reconstruction techniques, where temporal correlations in the dynamic imaging data are exploited to reduce k-space sampling necessary to generate an image (4, 5). Radial k-space sampling schemes are well suited for CS due to the presence of inherent incoherent aliasing artifacts, particular when using the golden-angle scheme (6). Recently we developed a novel reconstruction method that combines compressed sensing and parallel imaging for radial trajectories (k-t RASPS: RAdial SParse-Sense). Therefore, the purpose of this study was to assess the feasibility of performing free-breathing high spatial and temporal resolution imaging of the whole liver with radial golden-angle sampling and k-t RASPS reconstruction (GA-CS). Furthermore, our aim was to compare the signal-intensity-time curve of the GA-CS reconstructions to the regredded (RG) data sets, to investigate if temporal blurring effects occur in the CS reconstructions.

Materials and Methods: In this prospective HIPAA compliant IRB approved study, one healthy male subject (age 36 years) was imaged at 3T (MAGNETOM Verio, Siemens AG, Erlangen, Germany). MR acquisition was initiated simultaneously with intravenous injection of 10 cc of gadopentate dimeglumine (Magnevist; Berlex Laboratories, Wayne, NJ) followed by a 20-ml saline flush, both injected at a rate of 2cc/second with an MR-compatible power injector. A 3D stack-of-stars continuous GA radial trajectory was used for imaging with following parameters: FOV=380 x 380 mm, base resolution = 384 x 384, slice thickness = 3 mm, voxel size 1 x 1 x 3 mm, flip angle = 12°, TR/TE = 3.9/1.7 ms, and BW = 620 Hz/pixel. 600 spokes were acquired for each partition and 30 partitions were acquired to cover the whole liver. Images were reconstructed with interpolation to 60 slices. Total scanning time was 77 seconds, and the volunteer was allowed to breathe freely during the entire acquisition.

Image Reconstruction: Dynamic time series with high temporal resolutions were generated by grouping 13 (a Fibonacci number) adjacent spokes as one time point, which are then gridded into images with matrix size 384 x 384 x 46 resulting in a temporal resolution of 1.5 seconds. Reconstruction was performed using k-t RASPS by minimizing the functional $\|R \cdot E \cdot x - y\|_2 + \lambda \|T \cdot x\|_1$, where y is the undersampled k-space data, x is the image to be reconstructed, T is total variation along the temporal domain, and E is an operator that incorporates multiplication by the coil sensitivities, Fourier transformation, and a projection to the sampling locations in k-space. Further, R is a gridding operator that interpolates onto spokes in k-space. Reconstruction was performed in MATLAB (MathWorks, MA) using a nonlinear conjugate gradient algorithm. Coil sensitivity maps were calculated with the adaptive coil-combination method (7) using the temporal average of the gridded images as calibration reference. **Image Analysis:** A board-certified radiologist with 5 years of experience placed small (approximately 10 mm) regions-of-interest (ROI) in the aorta, main portal vein, and the liver parenchyma at the level of the porta-hepatis on a venous phase acquisition (to ensure visualization of the venous structures). These ROIs were transferred to the entire dynamic series for both the GA-CS reconstruction and the RG data set (without image registration). Signal intensity-time curves of the RG data set served as the reference to which GA-CS SI-time curves were compared and root mean square difference was calculated.

Results: Selected time points from the dynamic series through a single slice in the middle of the liver demonstrate excellent overall image quality (Figure 1). SI-time curves extracted from GA-CS show qualitatively similar curve shapes but appear slightly smoothed (or less noisy) compared to the RG data sets (Figure 2) although RMSD values are small (as shown in the table).

Conclusion: Dynamic contrast-enhanced perfusion imaging of the liver during free breathing with high temporal and spatial resolution is feasible using continuous golden-angle sampling and k-t RASPS compressed-sensing reconstruction. The fidelity of the SI-time curves still needs further investigation, but the proposed technique notably overcomes some of the major limitations of the conventional acquisition techniques.

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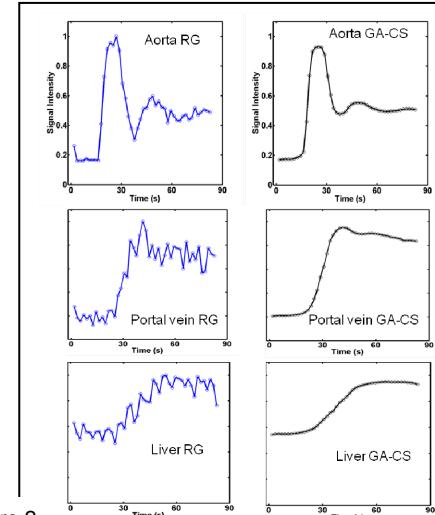
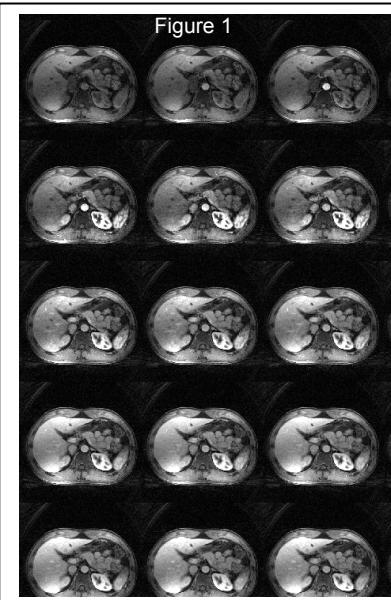


Figure 2

GA-CS and RG	Aorta	Portal Vein	Liver
RMSD	0.00254	0.019274	0.00330
% relative RMSD (compared to mean)	0.53%	3.48%	0.43%

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