

Optimizing Acquisition and Reconstruction for a Narrower Temporal Footprint in Time-Resolved 3DPR Liver Perfusion

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INTRODUCTION

Detection, characterization, and monitoring of hepatocellular carcinomas (HCC) in cirrhotic patients is challenging due to their variable and rapid arterial enhancement (1). Multi-phase contrast-enhanced (CE-MRI) is used clinically for HCC assessment, but suffers from limited temporal resolution and difficulty in coordinating breath-hold acquisition with contrast arrival. Because these techniques acquire only a few time points, quantitative perfusion modeling is challenging. Early efforts to supplant multi-phase CE-MRI using a time-resolved undersampled multi-echo 3DPR technique with quantitative perfusion modeling (2) offered significantly improved spatial and temporal resolution, but were limited by artifacts and SNR degradation that hindered detection of small HCC lesions. In order to achieve adequate image quality, a wide temporal footprint was required, compromising temporal fidelity in depicting small lesion enhancement. In this work, we discuss improved k -space sampling trajectories and the incorporation of a constrained reconstruction algorithm, leading to substantially improved temporal resolution and image quality.

METHODS

Healthy volunteers were scanned on a clinical 3.0T scanner (MR750, GE Healthcare, Waukesha, WI) using a 32-channel phased array torso coil (Neocoil, Pewaukee, WI). A time-resolved undersampled 3DPR (projection) spoiled gradient-recalled echo (VIPR-SPGR) acquisition was used with a 180 s acquisition with 4 half-echoes, 12° flip, ± 250 kHz bandwidth, coverage of the entire lower chest and liver with 2.1 mm isotropic spatial resolution, and one interleaved sub-frame acquired every second. After injection of 0.1 mmol/kg MultiHance at 2 ml/s followed by a saline flush, a real-time 3D fluoroscopic system (3) aided in coaching the subject through three 20-25 s breath-holds during the standard phases of liver enhancement: arterial, portal-venous and delayed. Image reconstruction was performed with an auto-calibrated iterative SENSE algorithm. Sensitivity maps were estimated from the central k -space data of all projections and a weighted least square, conjugate gradient algorithm was utilized to solve for the image (4). Weighting was chosen to emphasize the central echoes by penalizing inconsistencies with respect to the central echo greater than inconsistencies with respect to the first and last half-echoes. Hermitian symmetry was enforced by penalizing rapid changes in phase (5). Images were reconstructed with the full 2.1 mm isotropic resolution at 1 s intervals using a 4 s temporal footprint. For comparison, images were also reconstructed at the same spatial resolution using the previous single-pass recon with a temporal resolution of 4 s for low spatial frequencies and 16 s for high ones, as well as using the iterative algorithm with a flat weighting that did not penalize inconsistency.

RESULTS AND DISCUSSION

Improved matching between the acquired resolution and the desired reconstructed resolution allowed 40% more views to be collected per interleave with minimal change in reconstructed resolution or SNR, reducing undersampling artifacts. The iterative reconstruction allowed a significantly narrower temporal window compared to the previously used “tornado filter” - the previous exams had an effective temporal footprint of 16 s, whereas the results presented here use a sliding window with a true temporal footprint of 4 s. This substantially improves the fidelity of contrast uptake curves for small features (important for subsequent quantitative modeling) and increases robustness to respiratory motion. The algorithm effectively combines data acquired at varying echo times (even in the presence of phase inconsistencies due to off-resonance spin in areas of B_0 inhomogeneity) and is robust to inconsistencies from respiratory motion.

This study demonstrates continued progression in the image quality achievable in liver perfusion imaging using 3DPR techniques. Iterative constrained reconstruction and improved acquisition efficiency allow a substantially narrowed temporal aperture for reconstruction, with image quality somewhat improved over previous work. Consistency weighting allows efficient use of data from all four half-echoes, reducing signal loss in areas of the liver with poor B_0 inhomogeneity, without the need for the multifrequency reconstruction used previously.

We have presented a method to image the entire liver for perfusion measurements with true 4 s temporal resolution. This development provides the foundation for our upcoming perfusion analysis of 75 HCC patients undergoing new drug therapies aimed to slow tumor perfusion over the next year.

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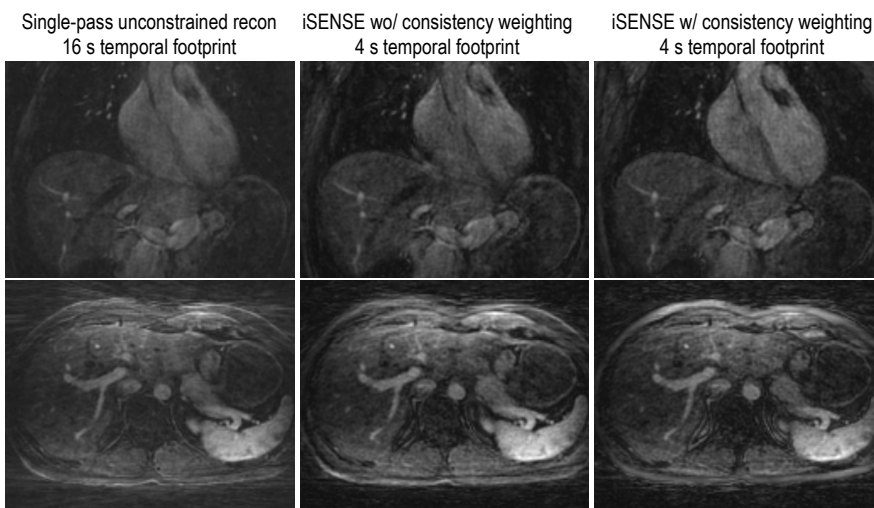


Figure 1: Coronal and axial reformatted slices from a volunteer exam show the improved image quality and temporal resolution gained with the new acquisition and reconstruction techniques. All three images are reconstructed from the same late arterial time frame using the same raw data. The images at left were generated using the previous single-pass recon and had a temporal footprint of 16 s. The center and right columns show images generated from the same dataset using the iterative SENSE processing, using only a 4 s temporal aperture, both without (center) and with (right) consistency weighting. The iSENSE images compare favorably to the conventionally reconstructed images, even though they're reconstructed using only a fraction of the data, with the consistency weighting yielding further improvements, especially in regions where off-resonant signal is present. It is clear that the iterative reconstruction allows for substantial reductions in temporal footprint without compromising image quality.