High Frame Rate 3D Dynamic Contrast Enhanced Imaging of the Liver with Continuous Acquisition

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INTRODUCTION

Dynamic Contrast Enhanced (DCE) liver perfusion imaging is a powerful tool for detection and assessment of liver lesions, including hepatocellular carcinoma (HCC) [1]. Current clinical methods acquire multiple 3D volumes during short breath-hold intervals, with the goal of timing the first acquisition with the late arterial phase when the contrast-to-noise ratio (CNR) between liver and enhancing tumors is maximized; subsequent acquisitions are timed to interrogate for contrast washout in enhancing lesions for lesion characterization. Conventional imaging generally has adequate spatial resolution, but very poor temporal resolution, and suffers from inconsistent timing of the late arterial phase. Previous work has used an interleaved variable density (IVD) sampling pattern and a highly constrained Cartesian reconstruction (HYCR) in conjunction with parallel imaging to acquire DCE images of the liver with high spatial and temporal resolution [2].   In this work, we augment the IVD-HYCR method with fluoro-triggering [3] and enable continuous scanning during the passage of the contrast agent with retrospective identification of multiple breath-hold start times and durations, increasing the method's ability to accurately and consistently acquire high frame-rate images with optimal contrast timing.

METHODS

Three healthy volunteers and one patient with known HCC were scanned on a 3.0T MRI system (Discovery MR750, GE Healthcare, Waukesha, WI) after informed written consent was obtained in accordance with our Institutional Review Board guidelines. 0.1 mmol/kg of gadobenate dimeglumine (Multihance, Bracco, Princeton, NJ) was administered at 2mL/s. When the contrast agent was observed in the right ventricle of the heart during

Figure 1: a) Elliptical Centric IVD sampling pattern for the first time frame with fully-sampled center and pseudorandomly-undersampled outer region of k_y-k_z-space. b) Breath-holding periods from respiratory bellows signal obtained during 3 minutes of scanning. Center of k_y-k_z-space is sampled 8 times during the first breath-hold whereas the periphery is sampled with different interleaved undersampling patterns.

fluoro monitoring, the 3D acquisition was initiated by the operator and the volunteer was asked to hold their breath as long as possible, followed by alternating periods of free-breathing and breath-holding during the remainder of the scan. Different interleaves of the IVD sampling pattern (*Fig. 1*) were acquired continuously for the duration of the three minute scan and the waveform of the respiratory bellows was recorded. Imaging parameters for the 3D SPGR acquisition included: flip angle=12°, TR/TE= 3.8/1.3ms, 75% fractional echo, FOV=40 cm (R/L) × 28 cm (A/P) × 20 cm (SI), matrix= 320×258×100, for 1.2 x 1.2 x 2.0mm³ true spatial resolution over the entire liver with 4s temporal resolution.

The IVD sampling pattern (*Fig. 1a*) was fully sampled at the center of k_y-k_z-space, but the higher spatial frequencies were undersampled to achieve 3x2 (R=6) parallel imaging and were further undersampled pseudo-randomly per interleave (R=4) yielding a total acceleration factor of R=24. Breath-hold intervals were retrospectively identified using the bellows waveform (*Fig. 1b*) to restrict view sharing of high spatial frequency data to within each breath-hold interval.

RESULTS AND DISCUSSION

Figures 2a-d show 4 of 8 time-resolved images acquired during the first breath-hold interval from a patient with metastatic HCC three weeks into treatment with sorafenib, an anti-angiogenic drug. Numerous enhancing tumors are seen throughout the liver. The expected pattern of contrast arriving into the aorta, spleen, portal vein, and liver parenchyma can be appreciated. These image and image data acquired in subsequent breath-hold intervals (not shown) demonstrate that multiple high resolution volumes can be obtained during each breath-hold (depending on length of breath-hold). *Figures 2e-f* show the coronal and sagittal reformats of one the frames.

CONCLUSION

In this work, we have demonstrated a novel approach to acquire dynamic contrast-enhanced images of the liver with high temporal (~4s) and spatial resolution (1.2 x 1.2 x 2.0mm³). Fluoro-triggering maximizes the amount of useful data acquired during the first breath-hold when the initial arterial phase of contrast enhancement occurs. Continuous scanning during multiple breath-holds and use of data sharing enables acquisition of i) high spatial and temporal resolution images and ii) numerous time frames, permitting more complete assessment of contrast dynamics.
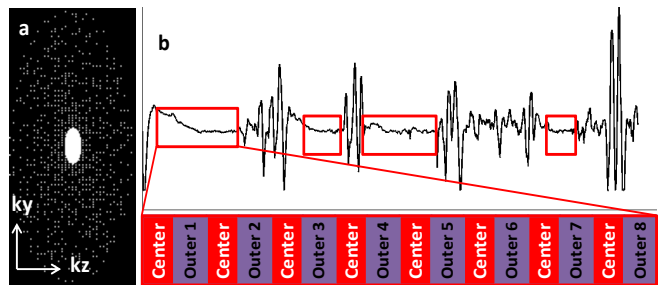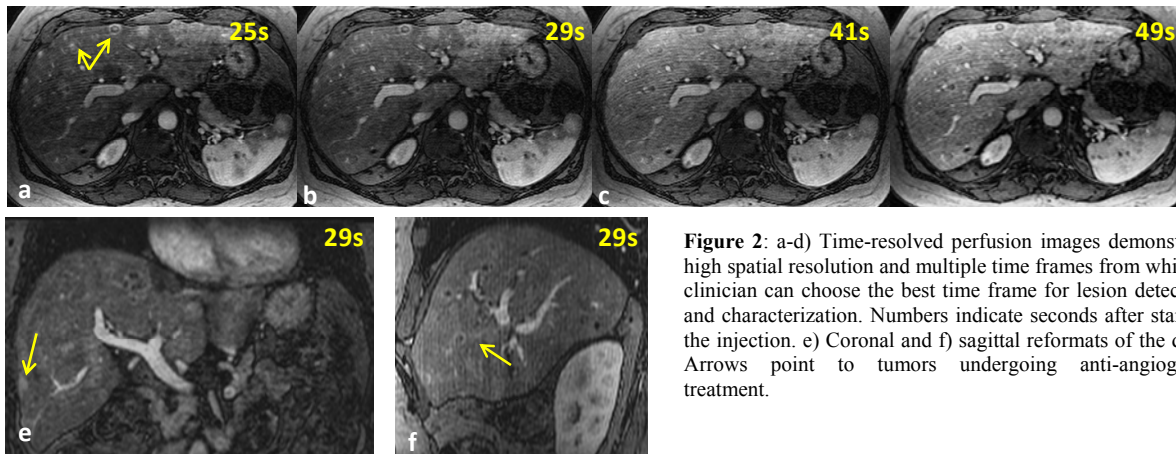

Figure 2: a-d) Time-resolved perfusion images demonstrate high spatial resolution and multiple time frames from which a clinician can choose the best time frame for lesion detection and characterization. Numbers indicate seconds after start of the injection. e) Coronal and f) sagittal reformats of the data. Arrows point to tumors undergoing anti-angiogenic treatment.

REFERENCES [1] Materne et al., MRM 2002; 47:135-142 [2] Wang et al., ISMRM 2011; 3459 [3] Wilman et al., Radiology 1997; 205: 137-146