Interleaved Variable Density Sampling for Combined Dynamic Contrast Enhanced MRI and MRA of the Liver

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TARGET AUDIENCE: Physicists and clinicians interested in time-resolved and dynamic contrast enhanced (DCE) and MRA of the liver

PURPOSE: DCE MRI is sensitive and specific for detection and characterization of focal liver lesions [1]. A variety of rapid imaging techniques [2-4] have been previously used to improve spatial and temporal resolutions of contrast enhanced liver MRI. The ***purpose of this work*** was to develop and validate a highly accelerated Cartesian undersampling strategy for 3D imaging of the liver during the passage of a gadolinium-based contrast agent (GBCA). Furthermore, MR angiograms of the hepatic and mesenteric arteries were obtained from the same dataset without the need for an extra injection of GBCA.

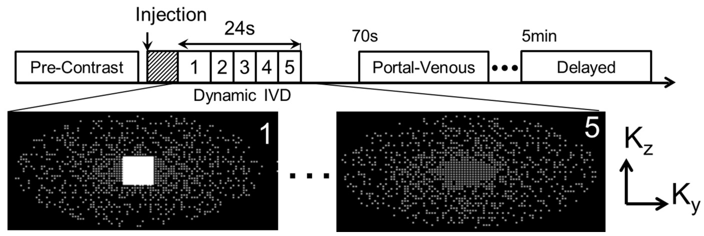

FIG1. IVD sampling pattern is used during the arterial phase for rapid, high resolution, dynamic liver imaging. Parallel imaging calibration lines are acquired only once during the breath-hold. Hashed box denotes the real-time triggering of acquisition using a monitoring volume (SmartPrep) in the right ventricular outflow tract.

METHODS: *Patients:* In this HIPAA compliant, IRB approved, prospective study, ten patients (M/F = 3/7, age 42 ± 11 years) with known focal nodular hyperplasia (FNH) were recruited after informed written consent was obtained. *Pulse Sequence:* An undersampled interleaved variable density (IVD) pattern [5] was used with a 3D spoiled gradient recalled acquisition at 3T (Discovery MR750, GE Healthcare, Waukesha, WI). Data-driven parallel imaging (DPI) [6] was used for additional acceleration. Autocalibration signal (ACS) lines were acquired only once during the first time-frame in a series to minimize the breath-hold time. A total effective acceleration factor of 16.8 was achieved. Readout lines were ordered using an edge-center-edge scheme within every time-frame. ***Figure 1*** shows a schematic of the proposed imaging protocol. Further, a dual-echo bipolar readout was used for 2-point Dixon fat-water separation [7]. Real-time triggering (SmartPrep) from the right ventricle was used to account for variability in arrival time of the contrast agent to the liver. *Imaging Parameters:* axial excitation, FOV = 38 cm (R/L) × 34 cm (A/P) × 26 cm (S/I), true spatial resolution of 1.2 mm (R/L) × 1.7 mm (A/P) × 2.6 mm (S/I), flip angle=15°, bandwidth = ±166.7 kHz, TR/TE1/TE2 = 3.9/1.2/2.3 ms, and R = 2 × 2 DPI. 0.1 mmol/kg of gadobenate dimeglumine (Multihance, Bracco Diagnostics, Monroe, NJ) was administered at 2 mL/s followed by 50 mL of saline flush. A dedicated high resolution MRA of the abdomen was obtained using a second injection of 0.1mmol/kg of gadobenate at the same rate, 20 min after the first injection. *Data Analysis:* images were graded using a 5-point visual score based on overall image quality by two radiologists. The grades were compared to the grades from prior clinical DCE MRI (single 3D fat-suppressed image during the arterial phase) using a paired two-sided t-test. The angiographic performance of the proposed IVD method was assessed in 11 hepatic and mesenteric arterial segments using a similar scoring scale. Scores were compared to scores from assessment of the dedicated MRA using a one-sided t-test.

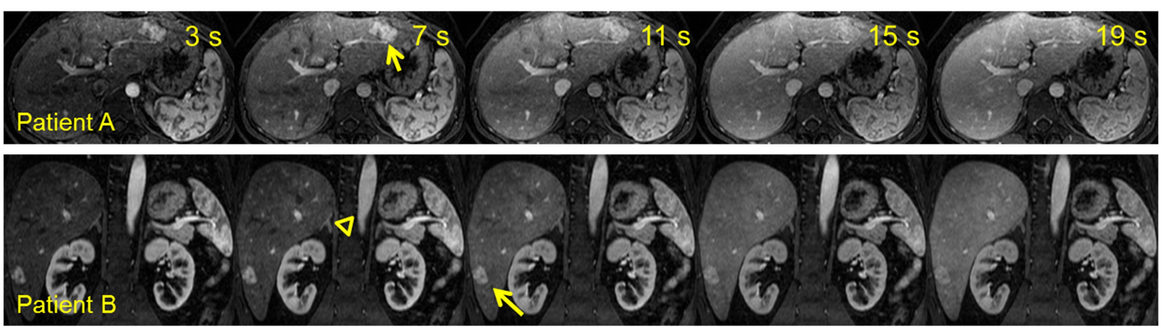

FIG2. Excellent image quality was achieved in all patients. Rapid uptake of GBCA is visible in the FNH lesions (arrows), liver parenchyma, spleen, renal cortex, and medulla in two patients in the axial and reformatted coronal planes. Note the lobular margins of both FNH. Also note depiction of the adrenal glands (arrowhead) in the coronal reformatted images.

RESULTS: The acquisition was successful in all 10 subjects, in whom a total of 21 FNH and 3 cavernous hemangiomas were identified. In each patient, a set of 5 time-frame images with update time of 4 seconds was obtained within a single breath-hold during the arterial phase. ***Figure 2*** shows cropped images from two patients. Images were graded as having significantly higher quality (4.0, 3.9) compared to the clinical MRI (2.8, 2.0) (P<0.01 for both readers). Both readers preferred the IVD method over the clinical method in all patients. Angiograms produced from the IVD datasets had non-inferior arterial segment visibility, compared to the clinical MRA (P=0.01 and P=0.03, for readers 1 & 2). ***Figure 3*** shows a limited-slab MIP MRA from the arterial time-frame of the IVD series.

DISCUSSION: A time-resolved IVD pattern was successfully used to acquire a series of high resolution images of the abdomen during a breath-hold. The images were used to visualize FNH in a group of patients and abdominal MRAs were successfully obtained from the same dataset. Cartesian-undersampled liver imaging has been further improved by use of i) a modified sampling pattern (IVD) ii) a new strategy for acquiring ACS lines (first time-frame only) and iii) real-time triggering.

CONCLUSION: The feasibility of obtaining very high spatial (1.2 x 1.7 x 2.6 mm^3) and temporal (4s) resolution dynamic phase MRI of the liver in a single breath-hold with excellent image quality is demonstrated. Further, simultaneous MR angiography may obviate the need for an additional injection of GBCA.

REFERENCES: [1]Burrel et al. Hepatol. 2003;38(4):1034-1042 [2]Saranathan et al. JMRI 2012;35(6):1484-1492 [3]Brodsky et al. 2013:*available online* [4]Xu et al. MRM 2013;69(2):370-381 [5]Wang et al. MRM 2011;66(2):428-436 [6]Brau et al. MRM 2008;59(2):382-395 [7]Ma MRM 2004;52(2):415-419

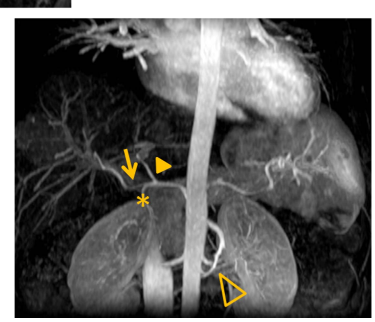

FIG3. High quality MR angiograms were possible using an arterial phase (typically the first time-frame) of the IVD time-series, in all patients. On this MIP, note the clear delineation of a variant of the trifurcation of the common hepatic artery into right hepatic artery (arrow), left hepatic artery (filled arrowhead) and gastroduodenal artery (*). Also clearly depicted is the variant of two left renal arteries (hollow arrowhead).