Respiratory motion-resolved compressed sensing reconstruction of free-breathing radial acquisition for improved dynamic liver MRI with hepatobiliary contrast agent

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Target Audience: Clinicians and basic scientists interested in contrast-enhanced abdominal MRI

Purpose: Hepatobiliary contrast agent Gd-EOB-DTPA is increasingly used for evaluation of focal liver lesions in cirrhotic and non-cirrhotic patients[1,2]. Assessment of arterial enhancement is key to diagnosing and characterizing hepatic lesions. Hence optimal timing of the arterial phase and acquisition of multiple arterial phases is desired given variable enhancement pattern of liver lesions. However, need to acquire data within a breath-hold limits temporal and spatial resolution, as well as volumetric coverage. These concerns are accentuated with Gd-EOB-DTP due to its lower contrast dose, lower injected volume, and slower injection rate compared with other commonly used contrast agents. Furthermore, recent reports of transient dyspnea associated with this contrast agent have amplified timing concerns[3]. GRASP (Golden-angle RAdial Sparse Parallel), a recently proposed free-breathing imaging technique combining compressed sensing and parallel imaging, can help overcome many of the above limitations[4]. A recent study showed diagnostic image quality of the arterial and venous phase GRASP, but overall lower image quality compared to conventional breath-hold acquisition in healthy volunteers[5]. This lower image quality is likely related to the motion averaging effects that are associated with radial sampling. In order to improve image quality, in this study we used the newly-introduced XD-GRASP technique (eXtra-Dimensional Golden-Angle RAdial Sparse Parallel imaging)[6] which sorts the acquired data into an extra respiratory motion dimension using respiratory motion signals extracted directly from the acquired data and employs a compressed sensing reconstruction algorithm that exploits sparsity along the respiratory motion dimension and the contrast-enhancement dimension to generate motion resolved dynamic Gd-EOB-DTPA images. We compare the image quality of multiphase dynamic XD-GRASP and GRASP reconstructions to prior conventional breath-held multiphase acquisitions in patients undergoing clinically indicated Gd-EOB-DTPA enhanced liver MRI.

Methods: In this prospective HIPAA compliant IRB approved study, 16 patients undergoing clinically indicated liver MRI at 1.5-T with the Gd-EOB-DTPA contrast agent, who also had prior conventional Cartesian breath-hold exams, were imaged during contrast injection with a continuous golden-angle radial stack-of-stars acquisition scheme. 1904 radial spokes were acquired continuously in 318-340 sec. Imaging parameters: slice thickness = 3 mm, flip angle = 12°, FOV = 385 x 385 mm^2, image matrix = 256 x 256, partial-Fourier along the slice-encoding dimension, spatial resolution = 1.5x1.5x3 mm^3 (interpolated), TR/TE = 3.97-4.29 ms/1.71 ms, 72 partitions (interpolated), bandwidth = 450 Hz/pixel. Intravenous injection of 10 mL Gd-EOB-DTPA (Eovist, Bayer HealthCare) was initiated 20 seconds after commencement of scanning at a rate of 1 mL/s, followed by a 20 mL saline flush.

GRASP/XD-GRASP Reconstruction: GRASP reconstruction was performed by grouping 84 consecutive spokes in each frame to achieve temporal resolution of ~14 seconds by enforcing joint multicoil sparsity along the contrast-enhancement dimension, as previously described[4]. For XD-GRASP reconstruction, the 84 spokes corresponding to each contrast-enhancement phase were sorted into 4 respiratory phases (from end-inspiration to end-expiration) using a respiratory motion signal extracted from the data. Respiratory motion estimation was performed as follows: (a) 1D Fourier transform was applied to the central k-space points in each acquisition angle along the partition dimension to produce a projection profile of the entire volume along that dimension, (b) the projection profiles from all coils were concatenated into a two dimensional matrix, (c) principal component analysis was performed on the matrix to identify the main signal variation components, and (d) the principal component with the highest peak in the frequency range of 0.1-0.5Hz was selected to represent respiratory motion. XD-GRASP reconstruction was extended from the GRASP algorithm by enforcing an additional sparsity constraint along the extra respiratory-state dimension.

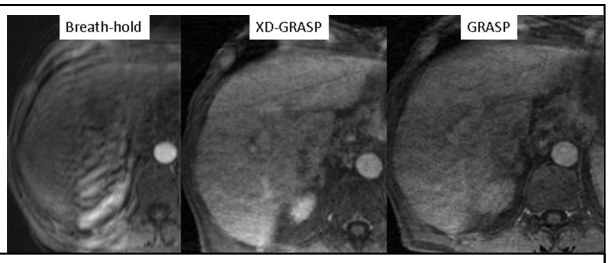

Figure: XD-GRASP reconstruction achieved higher image quality for arterial phase compared to GRASP or BH-VIBE

Image Analysis: Dynamic post-contrast XD-GRASP in an end-expiratory state and GRASP reconstructions for early arterial, late arterial and portal venous phases were anonymized and presented in DICOM format to two readers in random order. Readers compared image quality of the XD-GRASP, GRASP, and Cartesian acquisition in end-expiration breath-hold (BH-VIBE) for early arterial, late arterial and portal venous phase of enhancement. Image quality was scored on a 5 point scale (1-5), with a higher score indicating a better exam. Both readers also independently assessed for presence of enhancing lesions greater than 0.5 cm. If a lesion was identified, readers scored lesion conspicuity and lesion edge sharpness on a 5-point scale. A paired sample Wilcoxon signed rank test was used to compare acquisitions in terms of scores from each reader.

Results:

Overall Image Quality: XD-GRASP had higher overall image quality compared to GRASP for all phases of enhancement for both readers. Furthermore*, XD-GRASP also had higher image quality for early and late arterial phases of enhancement when compared to conventional breath-hold Cartesian acquisition.*

Lesion Evaluation: XD-GRASP had higher scores compared to GRASP for lesion conspicuity (Reader 1: 4.5 ± 0.67 versus 4.17 ± 1.03; Reader 2: 4.45 ± 0.52 versus 3.70 ± 1.16) and lesion edge sharpness (Reader 1: 3.92 ± 0.67 versus 2.92 ± 1.16; Reader 2: 4.27 ± 0.47 versus 3.50 ± 1.08). However, these differences did not reach statistical significance given the small number of lesions in this study (all $p \geq 0.06$).

Overall Image Quality	**GRASP**		**XD-GRASP**		**BH VIBE**	
Phase of Enhancement	*Reader 1*	*Reader 2*	*Reader 1*	*Reader 2*	*Reader 1*	*Reader 2*
Early Arterial	3.31 ± 0.6	3.38 ± 0.9	***4.3 ± 0.6***	***3.81 ± 0.8***	3.88 ± 0.6	3.50 ± 1.0
Late Arterial	3.63 ± 0.6	2.88 ± 0.7	***4.5 ± 0.6***	***3.56 ± 0.5***	3.44 ± 0.6	2.94 ± 0.9
Portal Venous	3.75 ± 0.8	3.81 ± 0.9	4.44 ± 0.5	4.0 ± 0.5	4.38 ± 0.6	4.0 ± 0.7

Table: XD-GRASP achieved higher scores of image quality compared to GRASP and BH-VIBE for arterial phases of enhancement

Conclusion and Future Directions: Our study has shown that XD-GRASP, which resolves respiratory motion within each contrast phase, has superior image quality and higher lesion conspicuity compared to standard GRASP reconstruction in patients undergoing dynamic liver MRI with hepatobiliary contrast agent Gd-EOB-DTPA. Furthermore, arterial phase XD-GRASP reconstructions have higher overall image quality compared to the conventional breath-hold Cartesian acquisitions. This has the potential to improve dynamic liver imaging in patients undergoing Gd-EOB-DTPA enhanced MRI.

References: **1**. Zech, C.J., et al. Invest Radiol, 2008. 43(7); **2**. Park, M.J., et al. Radiology, 2012. 264(3); **3**. Davenport, M.S., et al. Radiology, 2014. 272(1); **4**. Feng, L., et al. Magn Reson Med, 2014. 72(3); **5**. Chandarana, H., et al. Invest Radiol, 2013. 48(1); **6.** Feng L., et al. ISMRM 2013; 606