Clinical Performance and Validation of a Compressed Sensing Contrast Enhanced MRI with Fast Image Reconstruction

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INTRODUCTION: Recently high-density pediatric coils and compressed sensing (CS) have improved imaging of small abdominal structures in children [1-2]. We assess clinical performance of a rapid reconstruction compressed sensing algorithm that permits one-minute reconstruction times even with high-density coils [3].

METHODS:

Pulse Sequence/Image Reconstructions: A 3D SPGR sequence with intermittent fat suppression and Poisson-disc variable density k-space sampling was developed with TE~0.7-1.09ms, TR~3.6-4.4ms, 0.8-1mm slices, FOV~24-32 cm, matrix~288x288 or 320x320, and 7.2x acceleration. Post-contrast-images were acquired with a dedicated 32-channel pediatric high-density coil. For each subject, 3 reconstructions were done: (a) parallel imaging (PI) alone (ARC) [4], (b) a combination of PI and CS (L1-SPIRiT) [5], and (c) CC-L1-SPIRiT [6], a combination of L1-SPIRiT and coil compression. For coil compression, the acquired data are inverse Fourier transformed along the readout direction into (x, ky, kz, coil) space, where coil compression is performed at each x location. Data are compressed into 6 virtual coils from 32 original coils, and then Fourier transformed back into (kx, ky, kz, coil) space (Fig. 1). L1-SPIRiT reconstructions are performed on the virtual coils to fill the unacquired k-space data that reduces the 32 channel data to 6 virtual channels, thus enabling rapid reconstruction in under 1 minute despite high density coils instead of 7-8 minutes for L1-SPIRiT.

Patient Recruitment and Image Evaluation: With IRB approval/consent, 29 consecutive children referred for MRI were recruited (ages 0.2-6.92 yrs; mean ± S.D=3.79± 0.39 years). Two radiologists blinded to reconstruction type graded images for qualitative SNR, structural artifacts, image contrast, image blurring, synthetic appearance and quality of delineation of specific structures (renal artery, liver, portal vein, hepatic veins, pancreatic duct, adrenal gland, & spine). In randomized blinded order, the reconstructions were first presented individually and then in pairs for direct comparison.

Statistical Analyses: A binomial test assessed differences in quality of structural delineation and blurring between paired reconstructions. A one-sample z-test assessed the nondiagnostic rate for each image quality assessment for individual reconstructions is at least 10%. A paired Wilcoxon rank sum test (PWRST) assessed differences in image quality and delineation of structures between ARC & L1-SPIRiT, ARC & CC-L1-SPIRiT, and L1-SPIRiT & CC-L1-SPIRiT, when assessed individually. Weighted κ statistics assessed observer agreement.

RESULTS:

Overall Image Assessments:

a. Individual Assessments: All L1-SPIRiT and CC-L1-SPIRiT cases had diagnostically acceptable SNR versus only 16/29 for ARC ($p< 0.05$, PWRST), but structural artifacts were less with ARC vs L1-SPIRiT and CC-L1-SPIRiT (PWRST, $p<0.05$). Image contrast was superior with L1-SPIRiT and CC-L1-SPIRiT over ARC (PWRST, $p<0.05$). Structural artifacts and a synthetic appearance were more common with L1-SPIRiT and CC-L1-SPIRiT than ARC (PWRST, $p<0.05$)(Table 1).

b. Paired Comparisons: CC-L1-SPIRiT images were less blurred than L1-SPIRiT in 29/29 cases, and ARC images were less blurred than L1-SPIRiT in 27/29 cases (binomial test, $p<0.05$).

Delineation of specific structures:

a. Individual Assessments: Delineation for all anatomical structures was superior with both L1-SPIRiT and CC-L1-SPIRiT over ARC (PWRST, $P<0.05$)(Fig. 2).

b. Paired Comparisons: Delineation of all anatomical structures (Fig. 3) except the pancreatic duct was superior with L1-SPIRiT and CC-L1-SPIRiT over ARC (binomial test, $p<0.05$). Delineation of all structures except the spine was superior with CC-L1-SPIRiT over L1-SPIRiT (binomial test, $p<0.05$).

Inter-observer Agreement: Weighted κ mostly ranged from 0.4 to 1.0, indicating overall good agreement between graders.

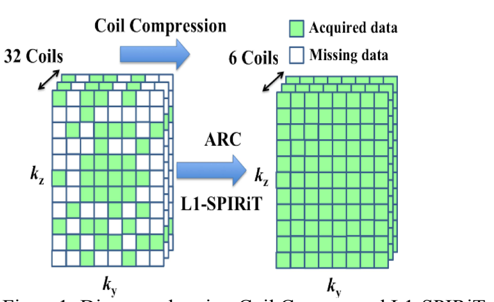

Figure1: Diagram showing Coil Compressed L1-SPIRiT.

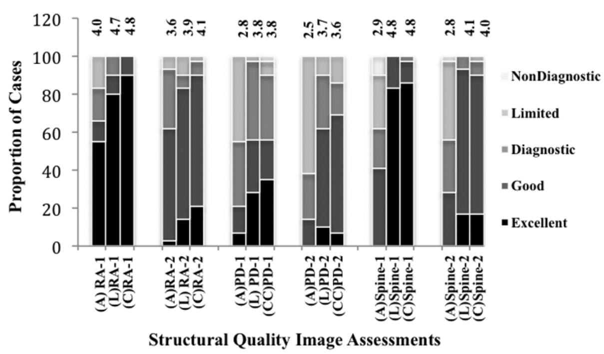

Figure2.Representative results of blinded randomized scoring of quality of structural delineation for some of the structures-Renal Artery (RA), Pancreatic Duct (PD) and Spine, validated for ARC (A), L1-SPIRiT (L), and CC-L1-SPIRiT(C) for Grader1(1) and Grader2 (2).

Qualitative SNR	C	5.0	L	4.9	A	2.6
Structural Artifacts	A	5.0	C	4.6	L	4.6
Image Contrast	L	4.0	C	3.9	A	3.9
Image Blurring	A	3.9	C	3.8	L	3.8
Synthetic look	A	4.0	L	3.5	C	3.1
Renal artery	C	4.8	L	4.7	A	4.0
Liver	L	4.7	C	4.6	A	3.3
Portal Vein	C	5.9	L	5.8	A	5.0
Hepatic veins	C	4.3	L	4.3	A	3.2
Pancreatic duct	C	3.8	L	3.8	A	2.8
Adrenal gland	C	4.5	L	4.4	A	3.3
Spine	C	4.8	L	4.8	A	2.9

Table1.Mean scores shown for ARC (A), LI-SPIRiT (L), and CC-L1SPIRiT (C). Statistically significant differences between scores are denoted by the thick red line. For image contrast and blurring, gray boxes (i.e.ARC and L1SPIRiT) had statistically significant differences.

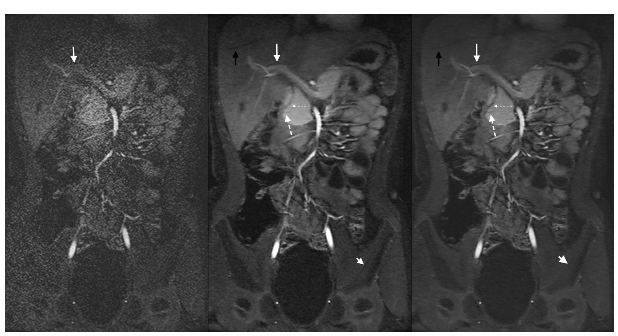

Figure3: ARC (left), L1-SPIRiT (middle), and CC-L1-SPIRiT (right) reconstructions of a 6-year-old female. Note delineation of hepatic vein branch (black arrow), portal vein (white arrow), pancreatic duct (large dashed arrow), bile duct (small dashed arrow), and cortex of left iliac bone (short white arrow).

CONCLUSION: Compressed sensing with fast image reconstruction is feasible in a pediatric clinical environment and can improve quality of structural delineation in pediatric MRI over parallel imaging. Coil compression does not adversely affect image quality.

REFERENCES:[1]Vasanawala SS et.al. Radiology 2010 256: 607-616 [2] Vasanawala SS et al. IEEE 2011 [3] Murphy M et al. ISMRM 2010 4854. [4] Beatty P et.al.2007 ISMRM 1749 [5] Lustig M et.al. MRM 2010; 64:457-471 [6] Zhang T et al. 2011 ISMRM 254.