Accelerated In Vivo 3D Chemical Exchange Saturation Transfer (CEST) Imaging using dynamic Compressed Sensing

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Target audience – Researchers interested in CEST imaging and applications of Compressed Sensing.

Purpose – Chemical Exchange Saturation Transfer (CEST) imaging is a recent technique with growing interest that allows for molecular imaging. This technique can detect low-concentration compounds with exchangeable protons through saturation transfer to water signal [1,2]. CEST may be combined with a 3D gradient echo-based readout to minimize distortion and to avoid slice-dependent saturation frequency variations. Since CEST requires the usage of a relatively long saturation pulse often for a series of multiple radiation frequencies, combination with 3D gradient echo readout is potentially limited in terms of spatial coverage [3]. One potential approach to overcome this limitation is to use compressed sensing (CS). In this study, we successfully obtained *in vivo* 3D image results using k-t FOCUSS [4] for 3D CEST imaging with balanced steady-state free precession (bSSFP) and fast imaging with steady-state precession (FISP) in a 3T human scanner. Experimental results show that CS acceleration by a factor of 4 works well for both 3D bSSFP-CEST and 3D FISP-CEST and improves the z-spectrum compared to parallel imaging method, which confirms that combination of CS may be a good solution for 3D- CEST imaging.

Methods – All experiments were performed on a 3 T whole body scanner (Siemens Medical Solutions, Erlangen, Germany). Two healthy male volunteers were imaged according to a study protocol approved by the local ethics committee. The CEST parameters were: RF pulse shape = Gaussian, flip angle = 180°, RF power = 0.6 μT, RF duration = 20ms, RF duty cycle = 50%, with 75 RF pulses applied for a total saturation period of 3s. The saturation was performed from -9.4ppm to 9.4ppm with 0.4ppm increments (-1200Hz to 1200Hz with 50Hz increments at 3T). The bSSFP experiments were conducted with a phase cycling angle of 180. The resolution parameters were the same for both 3D bSSFP and FISP: were: TR / TE = 4.02 / 1.77 ms, flip angle of 30°, bandwidth = 592 Hz/pixel, matrix size = 128 × 32 × 8, FOV = 240 × 240 × 40 mm^2, with slice oversampling = 25%. For 3D CEST with parallel imaging (PI) using GRAPPA, acceleration factor of 4 was used with reference PE line numbers of 24.

For CS application, a temporally varying down-sampling scheme with a fixed down-sampling factor of 4 was generated using a combination of uniform random and Gaussian probability distribution with full sampling of k-space center 6 lines (Fig.1) along the first PE (PE1) direction. CS reconstruction was performed using k-t FOCUSS algorithm [4]. The following k-t FOCUSS parameters were used for reconstruction: weighting matrix power factor (p) of 0.5, regularization factor (λ) of 0, Conjugate Gradient (CG) iteration number of 50, FOCUSS iteration number of 4, and no prediction.

Region of interest (ROI) was determined in the white and gray matter regions to compare the reconstruction between PI and CS for CEST imaging.

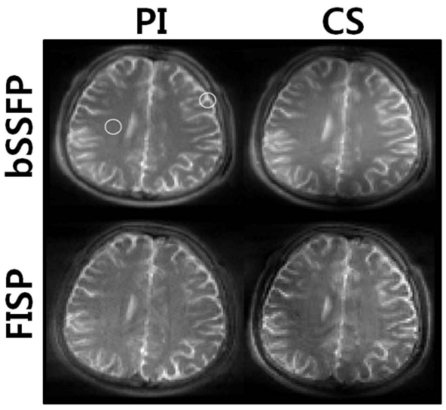

Fig 1 The baseline images after reconstruction. Left column shows a slice of multi-slice parallel imaging, and right is our reconstruction result. They are acquired by bSSFP and FISP. The down-sampled data were reconstructed by k-t FOCUSS. White circles show the ROI. (Left: white matter, Right: Gray matter)

Results & Discussion – The baseline images of 3D bSSFP-CEST and 3D FISP-CEST were reconstructed well using PI and CS (Fig.1). However, differences were observed between 3D CEST with PI and 3D CEST with CS when we plotted the z-spectrum for white and gray matter regions (Fig.2). For both 3D bSSFP-CEST and 3D FISP CEST, reconstruction using CS showed peaks from amide proton (3.5ppm), lipid (-3.5ppm), and Nuclear Overhauser Enhancements (NOE) (approximately -1 to -4ppm) in the z-spectrum obtained from the white and gray matter regions. The regional saturation peak around the lipid resonance frequency is especially observed in the z-spectrum of the gray matter, which is presumably due to the lipid in the skull. However, such peaks were not observed in parallel imaging reconstruction using GRAPPA, which supports that CS may be a valuable tool for 3D CEST imaging. Further studies are required to understand the signal contributions of saturation transfer and optimization of the CS algorithms.

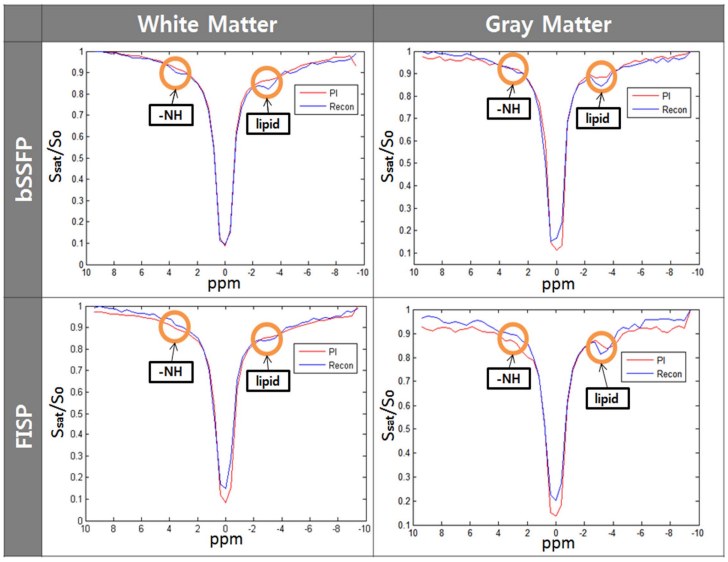

Fig 2 The z-spectrum for white and gray matter regions. The red line shows the z-spectrum of image from PI, and the blue line shows the z-spectrum of image from reconstruction.

Conclusion – In this study, we showed the usefulness of CS to 3D CEST imaging of human brain. Our results showed that compressed sensing approach were able to retain the z-spectrum peaks with acceleration by a factor of 4, whereas such peaks were missing in GRAPPA reconstruction.

References 1. Ward et al, J Magn Reson 143:79-87 (2000). 2. Ward and Balaban, Magn Reson Med 44:799-802 (2000). 3.He Zhu et al, Magn Reson Imag 64:638-44 (2010). 4. Jung et al, Magn Reson Med 61:103-11 6 (2009).