Highly-accelerated chemical exchange saturation transfer (CEST) measurements with linear algebraic modeling (SLAM)

Yi Zhang[1], Hye-Young Heo[1], Dong-Hoon Lee[1], Shanshan Jiang[1], Paul Bottomley[1], and Jinyuan Zhou[1,2]

[1]*Division of MR Research, Department of Radiolgoy, Johns Hopkins University, Baltimore, Maryland, United States,* [2]*F. M. Kirby Research Center for Functional Brain Imaging, Kennedy Krieger Institute, Baltimore, Maryland, United States*

Audience Scientists or clinicians interested in obtaining fast CEST measurements for differentiating brain pathology.

Purpose

CEST imaging has potential value for differentiating cancer[1-3], stroke[4,5], Parkinson's[6] and other human disease[7]. On the other hand, CEST imaging requires acquisition of saturation images at multiple frequencies and is slow. However, almost all human applications, e.g. for tumor grading[1-3], Parkinson's disease[6], creatine kinetics[7], and studying brain development, utilize compartmental average CEST indices. Here, the recently-proposed Spectroscopy with Linear Algebraic Modeling (SLAM) method[8,9] is adapted for ultrafast CEST MRI to directly reconstruct compartmental average indices or z-spectra. We demonstrate the feasibility of SLAM CEST with effective acceleration factors of up to 45-fold in brain tumor studies.

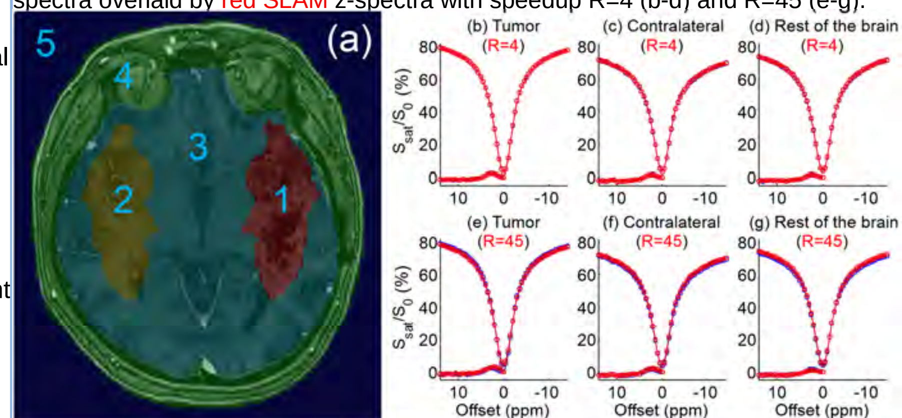
Methods

The central idea of SLAM[8,9] is to group voxels defined on scout MRI into *C* compartments, and reduce the number of *k*-space phase encodes to a subset of *C* chosen from central *k*-space. The compartment-average spectra obtain by solving the *C* simultaneous equations for the resulting subset of acquisitions. CEST SLAM was validated with CEST data from 6 brain tumor patients studied on a 3T Philips MRI system. CEST was performed with 4x200ms block saturation pulses (B_1=2μT) offset up to ±14 ppm from water at 0.5ppm steps, and WASSR[11] B_0 correction (2x200ms saturation at 0.5μT). One or 2 CEST MRI slices were acquired per patient using 2D TSE (turbo factor=45; SENSE[10] factor=2; FOV=212x186 mm; resolution=2.2x2.2mm; slice thickness=4.4mm; 7 data sets in total). FLAIR, T_1- and T_2-weighted clinical MRI were also acquired.

The *k*-space data were Fourier Transformed (FT) and unfolded in the phase encoding direction with the SENSE[10] algorithm for the "standard FT" reconstruction. "Standard FT" z-spectra for each voxel were generated after B_0 correction[1].

For "SLAM CEST" reconstruction, the CEST slice was co-registered with a clinical MRI, and segmented into different compartments (Fig. 1a). Compartmental average z-spectra were then reconstructed directly by the SLAM method[8,9] using the segmentation information and subsets of central *k*-space corresponding to various acceleration factors of R= 1-45. SLAM z-spectra, with both SENSE and B_0 corrections incorporated, were compared with "standard FT" z-spectra averaged over the same compartments.

Fig. 1: Five-compartment segmentation of a brain tumor image (a). Blue FT z-spectra overlaid by red SLAM z-spectra with speedup R=4 (b-d) and R=45 (e-g).

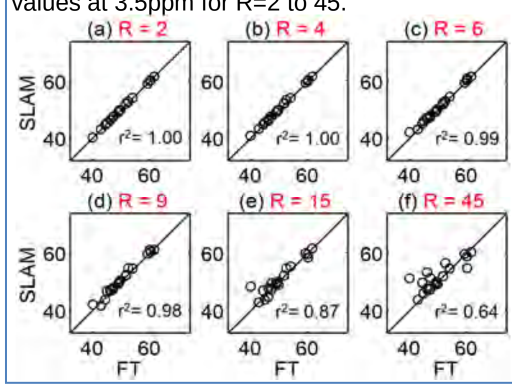


Results and Discussion

Fig. 1(a) shows segmentation of a co-registered T_1-weighted MRI from a tumor patient into 5 compartments (1: tumor, 2: contralateral, 3: "rest of the brain", 4: scalp, and 5: "other"). Fig. 1(b-g) show SLAM z-spectra reconstructed with acceleration factors of R=4 (Fig. 1b-d) and R=45 (Fig 1e-g), overlaid on "standard FT" z-spectra (blue) for compartments 1-3. <u>With R=45, SLAM used only a single phase encode</u>: the z-spectra are indistinguishable from "standard FT" spectra.

Fig. (2a-2f) compare "standard FT" and SLAM z-spectrum measures at 3.5ppm in the 3 compartments for different R-factors. The mean error was 0%, and the standard deviation vs. "standard FT" was ≤10% for R≤45.

Fig.2: (a-f) SLAM vs. "standard FT" z-spectrum values at 3.5ppm for R=2 to 45.



Conclusion

If compartment-average metrics suffice, SLAM can speed-up brain CEST studies up to 45-fold compared to the "standard FT" method. SLAM CEST measures agree with "standard CEST" within 10%, which can potentially be acquired in a 1 min scan that could facilitate clinical CEST in applications where scan time is limited, such as in pediatric cases.

References [1] Zhou J, et al. JMRI 2013. [2] Togao O, et al. NeuroOncolgy 2014. [3] Jia G, et al. MRI 2011. [4] Tietze A, et al. NMR Biomed 2013. [5] Tee YK, et al. NMR Biomed 2014. [6] Li C, et al. Eur Radiol 2014. [7] Haris M, et al. Nat Med 2014. [8] Zhang Y, et al. JMR 2012. [9] Zhang Y, et al. JMR 2013. [10] Pruessmann K, et al. MRM 1999. [11] Kim M, et al. MRM 2009. *Grant support: NIH Grant R01 EB007829, CA166171, EB009731*