Accelerated and motion-robust in vivo T_2 mapping from radially undersampled data using Bloch-simulation-based iterative reconstruction

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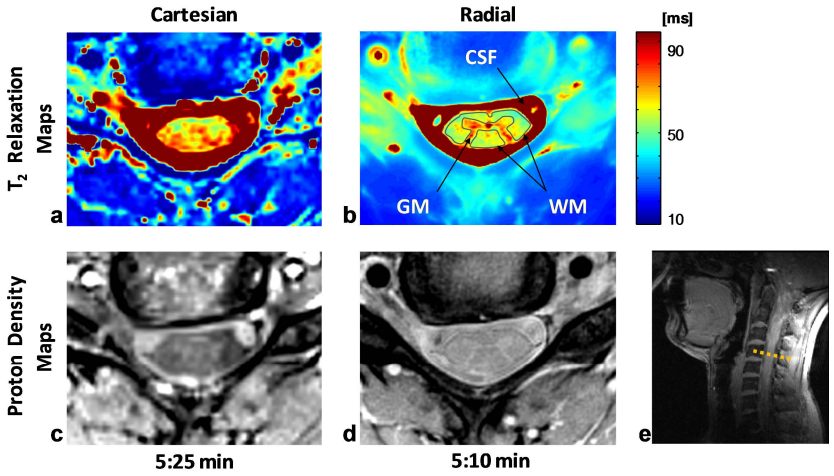
Target audience Clinicians interested in rapid quantitative T_2 mapping; Researchers interested in advanced motion robust image-reconstruction.

Purpose Quantitative mapping of T_2 relaxation time can be used to detect pathological tissue changes in various clinical applications including stroke[1], multiple sclerosis[2], cardiac imaging[3], cancer detection[4], and musculoskeletal imaging[5]. Still, routine use of traditional single spin-echo (**SSE**) protocols is impractical due to their long scan times, while faster, multi-SE (**MSE**) protocols, are inherently biased by stimulated echoes, non-rectangular slice profiles, and transmit field ($\mathbf{B_1^+}$) inhomogeneities. Recently a new technique – the echo-modulation curve (**EMC**) algorithm[6] – was introduced, which is able to overcome the typical penalties of MSE protocols, via precise Bloch simulation of the MSE pulse-sequence scheme. The approach is furthermore capable of producing T_2 maps in a fashion that is invariant to the scanner, protocol-implementation, or parameter set[7].

In this work we apply the numerical EMC model to radially sampled MSE offering additional benefits such as high acquisition efficiency, robustness to physiological motion, and ability to scan partial field-of-views. Moreover, due to its inherent high incoherence, the radial acquisition was accelerated by employing a multiparametric model-based reconstruction technique[8]. The resulting framework offers a high-resolution, accurate, and motion robust mapping of both T_2 and proton density (**PD**) values in clinically feasible scan times.

Methods EMC algorithm: Bloch simulations of the prospective MSE protocol were performed using exact sequence parameters, RF, and gradient waveforms. These were repeated for a range of T_2 and B_1^+ values (T_2=1…1000ms, B_1^+ = 50…130 % deviation from nominal value), producing a database of EMCs, each associated with a unique [B_1^+,T_2] value pair. Data were acquired on a whole-body 3T scanner (Siemens TimTrio) for **1)** an $MnCl_2$ phantom, **2)** in vivo brain (N=30), and **3)** in vivo spinal cord (N=5), using golden-angle radial MSE, Cartesian MSE and SSE protocols. Cardiac triggering (T_{delay}=10 ms) was used in the spinal cord scans. Acquisition parameters were: {***Radial MSE*****:** TR=2000ms, slice=3mm, echo-spacing=12ms, N_{echoes}=19, spokes per frame=100, res=1.1x1.1mm^2, T_{acq}=3:10min}, {***Cartesian MSE*****:** TR=2000ms, slice=3mm, echo-spacing=10ms, N_{echoes}=22, res=1.1x1.1mm^2, T_{acq}=3:10min (2x GRAPPA acceleration)} {***SE***: TR/TE=2000/15ms, slice=3mm, echo-spacing=15ms, $N_{echoess}$=6, res=1.7x1.7mm^2, T_{acq}=22min}. Reconstruction: ***Radial MSE:*** Joint three-parameter [B_1^+,T_2,PD] fit was performed by integrating the EMC database into the signal model of an iterative non-linear conjugate-gradient reconstruction algorithm[9]. ***Cartesian MSE*****:** T_2 maps were generated via pixel-by-pixel EMC fitting of the DICOM time-series produced by the Cartesian MSE. ***Cartesian SSE*****:** T_2 maps were generated via conventional pixel-by-pixel fitting of the DICOM time-series to an exponential $S(t)=S_0\exp(-t/T_2)$ relaxation model.

Results **$MnCl_2$ phantom:** excellent correlation was found between radial MSE and reference Cartesian data (p-value < 1e-9), for T_2 values ranging from 9ms to 120ms and refocusing flip-angles of [90°…180°]. **Brain T_2 maps** exhibited high correlation between radial and Cartesian MSE, with the former affording higher spatial definition per scan time. **Spinal cord:** Enclosed Figure shows axial T_2 and PD maps of the spinal cord in vivo, obtained using: (**a,c**) Cartesian MSE fitted using the EMC algorithm. (**b-c**) Radially undersampled MSE processed using an EMC-integrated model-based reconstruction. (**e**) Sagittal view of a fast spin-echo reference image showing the slice location. A clear advantage is seen for the radial data, allowing segmentation of the CSF and gray/white matter tissues.



Discussion The EMC algorithm offers fast and accurate extraction of the true sample T_2 values along with other parametric maps such as PD and B_1^+ in a fashion that is scanner and sequence invariant. This stability across scanners, protocol implementations and parameter values, is of further value for accurate T_2 quantification in longitudinal and multi-center studies with minimal inter-scan variability. The synergetic combination with radial sampling offers improved immunity to motion and allows acquisition at arbitrary spatial resolutions owing to the image-folding free nature of radial sampling. The radial EMC based model can be extended to include other contrasts such as T_1, diffusion and T_2^*, multi-compartment T_2 distributions, and various pulse-sequence designs.

References

[1] Siemonsen S et al. *Stroke* 2009; 40(5): 1612-16. **[2]** Lund H et al. *Acta Neurol Scand* 2012; 125(5): 338-44. **[3]** Eitel I et al. *J Cardiovasc Magn Reson* 2011; 13(1): 13. **[4]** Liu W et al. *MRM* 2011; 65(5): 1400-6. **[5]** Pan J et al. *Radiology* 2011; 261(2): 507-15. **[6]** Ben-Eliezer N et al. *MRM* 2014, doi: 10.1002/mrm.25156. **[7]** Ben-Eliezer N et al. ISMRM 2015 (submitted). **[8]** Block K et al. *IEEE Trans Med Imaging* 2009; 28(11): 1759-69. **[9]** Hager WW at al. *SIAM Journal on Optimization* 2005; 16: 170-192. **Financial support:** Helen and Martin Kimmel Award for Innovative Investigation. NIH Grant R01 EB000447.