569-04-002 ISMRM ABSTRACT

Multi-shot 2D Selective Excitation for Extracranial Lipid Suppression in MR Spectroscopic Imaging of the Brain

Digital Poster · 55 min View Poster | Spectroscopy: Acquisition and Reconstruction · Session: 2:35–3:30 PM · Digital Posters Row J · 2 **Keywords:** BRAIN MACHINE LEARNING/ARTIFICIAL INTELLIGENCE RF PULSE DESIGN & FIELDS MRSI METABOLIC IMAGING

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Impact

Achieving full brain coverage MRSI without lipid contamination is valuable for the adaptation of MRSI in clinical procedures. Our method of two-dimensional selective excitation allows for greatly reduced lipid contamination in MRSI without the need for post processing lipid removal.

Synopsis

Motivation: Magnetic resonance spectroscopic imaging (MRSI) enables non-invasive quantitative mapping of brain metabolite levels. However, lipid contamination from extra cranial adipose tissue severely compromises the quality of MRSI maps.

Goals: To reduce lipid contamination in full brain coverage brain MRSI through the use of multi-shot, two-dimensional excitation pulses (2DRF) that excite only the brain, and not extracranial adipose tissue.

Approach: Using a deep learning algorithm, 2DRF pulses are generated from a subject-specific brain mask, to avoid exciting the extracranial lipids.

Results: 2DRF brain-only excitation reduced lipid contamination by a factor of 100 in vivo, resulting in high-quality MRSI spectra and metabolite maps.

Introduction

Magnetic Resonance Spectroscopic Imaging (MRSI) is a versatile tool for investigating metabolism in brain pathologies including Alzheimer's, Multiple Sclerosis, and Cancer[1,2]. A significant challenge of performing MRSI on whole brain slices is the issue of lipid contamination. Extracranial lipids, found in the skin and adipose tissue of the scalp, produce MRSI signals with substantially greater amplitudes compared to the brain's primary metabolites. Extracranial lipid spectral signals tend to 'ring' into voxels within the brain, owing to the inherently low spatial resolution of MRSI. The dominant lipid spectral signal obscures the weaker spectral signals originating from common brain metabolites, such as NAA, choline, creatine, and myo-inositol, making accurate quantification difficult. To date, lipid contamination in whole brain-slice MRSI has been addressed by multiple methods including post-processing removal[3], outer-volume saturation (OVS) bands, and specialized hardware such as gradient crushers[4]. Each of these methods has unique limitations, however.

The goal of the present work is to investigate suppressing lipid contamination in MRSI using two-dimensional radiofrequency (2DRF) excitation pulses[5]. 2DRF pulses can potentially excite arbitrarily-shaped regions of interest (ROIs) to excite the brain exclusively, avoiding the scalp and allowing MRSI of whole brain slices without contamination from extracranial lipids[6]. Here, 2DRF pulses are generated in real time using a deep learning model that accounts for patient head shape, as well as B0 and B1+ inhomogeneities, with multi-shot excitation and readout to suppress off-resonance effects further[7,8]. The proposed method suppresses extracranial lipid signals without the need for OVS pulses or specialized hardware solutions, while simultaneously preserving intracranial signals of interest including lipids, macromolecules and lactate.

Methods

2DRF pulses were generated using a physics-informed, self-supervised deep learning model that jointly optimizes spiral gradient trajectories and RF waveforms[7] . The model was trained on a library of target polygonal ROIs, while accounting for B_0 and B_1^+ field inhomogeneities, using a differentiable Bloch simulator, enforcing physical constraints on RF amplitude and gradient slew rate; and extended to a multi-shot configuration[9] to output three sets of 2DRF and gradient waveforms corresponding to 3-shot spiral trajectory in excitation k-space. This approach enables sharp excitation transitions while permitting short pulse durations necessary for robust off-resonance behaviour. For each subject, a brain-shaped target ROI was manually segmented from an acquired T2-weighted anatomical image and then passed to the model. The model was fine-tuned using measured B_0 and B_1^+ maps to further ensure subject-specific excitation accuracy. The manually-segmented brain target was eroded 10 mm inwards to leave sufficient space between the excitation transition and the extra-cranial lipids for this proof-of-concept study. Figure 1 outlines the model framework.

A rapid slice-selective spin-echo MRSI sequence with a rosette k-space readout trajectory was modified by replacing the conventional slice selective excitation pulse with the subject-specific 2DRF exicitation pulse with associated trajectory gradients, and incorporating multi-shot excitation averaging. Figure 2 demonstrates the pulse sequence elements. The acquisition parameters were 240mm x 240mm FOV, 48x48 matrix size, 10mm slice thickness, TE 15ms, TR 1000ms, 6 averages, and 50^o flip angle on a 3T Siemens Prisma MRI system. The low flip angle was due to 2DRF amplitude peak constraints. The on-resonance excitation frequency was set to the frequency of lipids at -3.34ppm relative to water, such that the prescribed excitation profile did not degrade into the extra-cranial lipid region.

One healthy volunteer was recruited. Conventional MRSI was performed followed by 2DRF MRSI acquisition customized to brain shape.

Results

The MRSI data were first pre-processed using FID-A[10] and then analyzed using LCModel[11]. Metabolic maps of the lipid signals for both standard MRSI and 2DRF MRSI are compared in Figure 3. Normalized to the metabolic map of standard MRSI, 2DRF MRSI attenuates lipid signal by a factor of >100. In Figure 4, spectra from the standard MRSI and 2DRF MRSI are depicted in four selected voxels. Again, the 2DRF approach significantly reduces lipid

contamination in comparison to conventional MRSI. Finally, Figure 5 shows metabolite maps generated from 2DRF MRSI data, with corresponding maps of Cramér–Rao Lower Bound (CRLB) uncertainty estimates

Conclusion

Multi-shot 2DRF pulses have been demonstrated to excite arbitrary regions of interest for MRSI of the brain with significantly reduced lipid contamination. Future work will involve recruiting more healthy volunteers and also recruiting brain cancer patients to demonstrate effective suppression of extracranial lipids, and the detection of clinically-relevant intracranial lipid and lactate signals (which are suppressed by common post-processing lipid removal methods). Ultimately, the proposed method is expected to improve clinical MRSI applications by improved brain coverage with negligible extracranial lipid contamination

References

1. Graff-Radford J, Kantarci K. Magnetic resonance spectroscopy in Alzheimer's disease. Neuropsychiatr Dis Treat. 2013;9:687-96. doi: 10.2147/NDT.S35440. Epub 2013 May 16. PMID: 23696705; PMCID: PMC3658533. [pmid]

2. Narayana PA. Magnetic resonance spectroscopy in the monitoring of multiple sclerosis. J Neuroimaging. 2005;15(4 Suppl):46S-57S. doi: 10.1177/1051228405284200. PMID: 16385018; PMCID: PMC1351238. [pmid]

3. Lin L, Považan M, Berrington A, Chen Z, Barker PB. Water removal in MR spectroscopic imaging with L2 regularization. Magn Reson Med. 2019 Oct;82(4):1278-1287. doi: 10.1002/mrm.27824. Epub 2019 May 31. PMID: 31148254; PMCID: PMC6626566. [pmid]

4. Kumaragamage C, De Feyter HM, Brown P, McIntyre S, Nixon TW, de Graaf RA. Robust outer volume suppression utilizing elliptical pulsed second order fields (ECLIPSE) for human brain proton MRSI. Magn Reson Med. 2020 May;83(5):1539-1552. doi: 10.1002/mrm.28047. Epub 2019 Nov 19. PMID: 31742799; PMCID: PMC6982600. [pmid]

5. Pauly J, Nishimura D, Macovski A. A k-space analysis of small-tip-angle excitation. 1989. J Magn Reson. 2011;213(2):544-557. doi:10.1016/j.jmr.2011.09.023

6. Spielman D, Pauly J, Macovski A, Enzmann D. Spectroscopic imaging with multidimensional pulses for excitation: SIMPLE. Magn Reson Med. 1991 May;19(1):67-84. doi: 10.1002/mrm.1910190107. PMID: 2046539. [pmid]

7. Xiao, Y (2025, March 5-6) ,P5-07: Self-Supervised Parallel Transmit RF Pulse Design for 2D Spatially Selective Excitation [Poster Abstract]. Imaging Network of Ontario 2025, Toronto, Ontario, Canada

8. Jang A, He X, Liu F. Physics-guided self-supervised learning: Demonstration for generalized RF pulse design. Magn Reson Med. 2025 Feb;93(2):657-672. doi: 10.1002/mrm.30307. Epub 2024 Oct 9. PMID: 39385438; PMCID: PMC11604838. [pmid]

9. Panych LP, Oshio K. Selection of high-definition 2D virtual profiles with multiple RF pulse excitations along interleaved echo-planar k-space trajectories. Magn Reson Med. 1999 Feb;41(2):224-9. doi: 10.1002/(sici)1522-2594(199902)41:2<224::aid-mrm2>3.0.co;2-g. PMID: 10080266. [pmid]

10. Simpson R, Devenyi GA, Jezzard P, Hennessy TJ, Near J. Advanced processing and simulation of MRS data using the FID appliance (FID-A)-An open source, MATLAB-based toolkit. Magn Reson Med. 2017 Jan;77(1):23-33. doi: 10.1002/mrm.26091. Epub 2015 Dec 30. PMID: 26715192. [pmid]

11. Provencher SW. Automatic quantitation of localized in vivo 1H spectra with LCModel. NMR Biomed. 2001 Jun;14(4):260-4. doi: 10.1002/nbm.698. PMID: 11410943. [pmid]

Figures and Tables

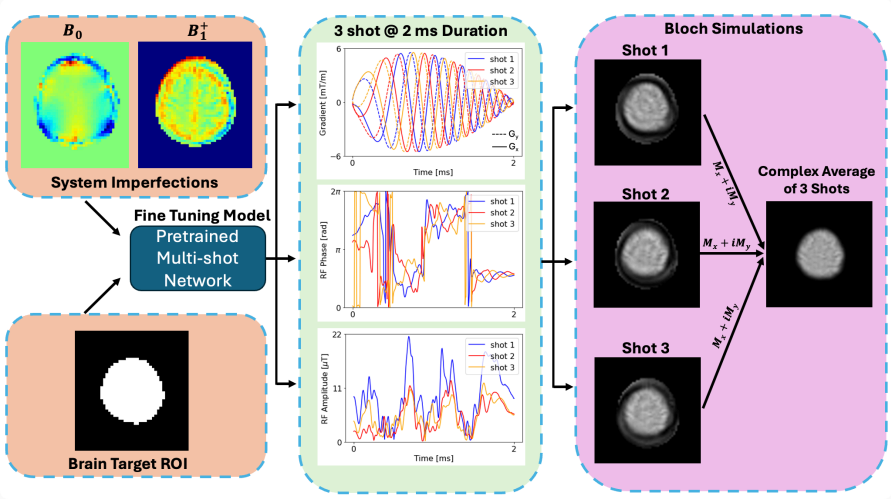

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Figure 1: *Overview of the 2DRF pulse and gradient waveform generation. B_0 and B_1^+ field maps are obtained prior to spectroscopic imaging. The pretrained multi-shot network is then fine tuned on the field maps, along with a brain target ROI. The Bloch simulations of each shot alone show the general excitation, along with residual excitations. The sum of the complex magnetization of each shot shows the final magnetization profile without any residual excitation.*

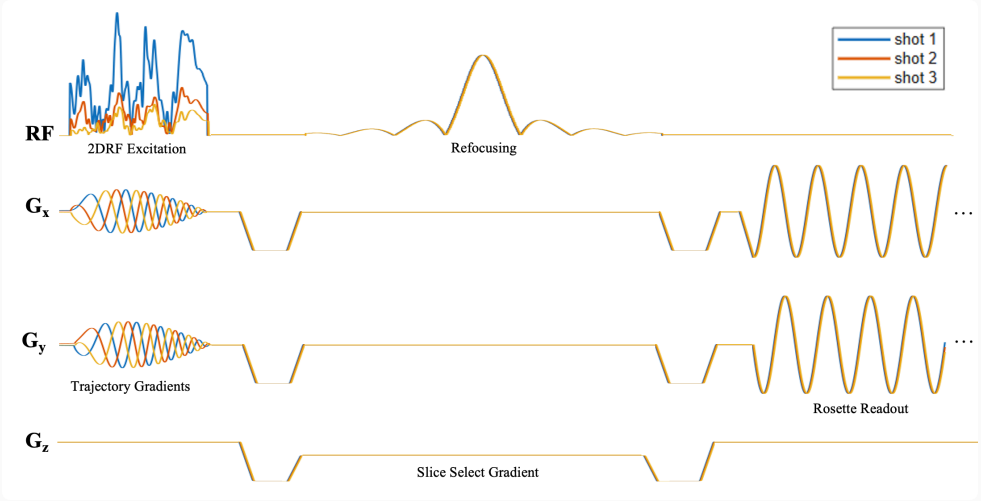

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Figure 2: *The pulse sequence elements for the selective excitation MRSI sequence; the conventional excitation was replaced by the 2DRF pulses and gradient trajectories. The rosette readout is unchanged for shots one to three, while the 2DRF pulses and gradient trajectores are interleaved. A refocusing pulse with a slice select gradient allows for slice selection as 2DRF pulses only excite a column orthogonal to the trajectory axis.*

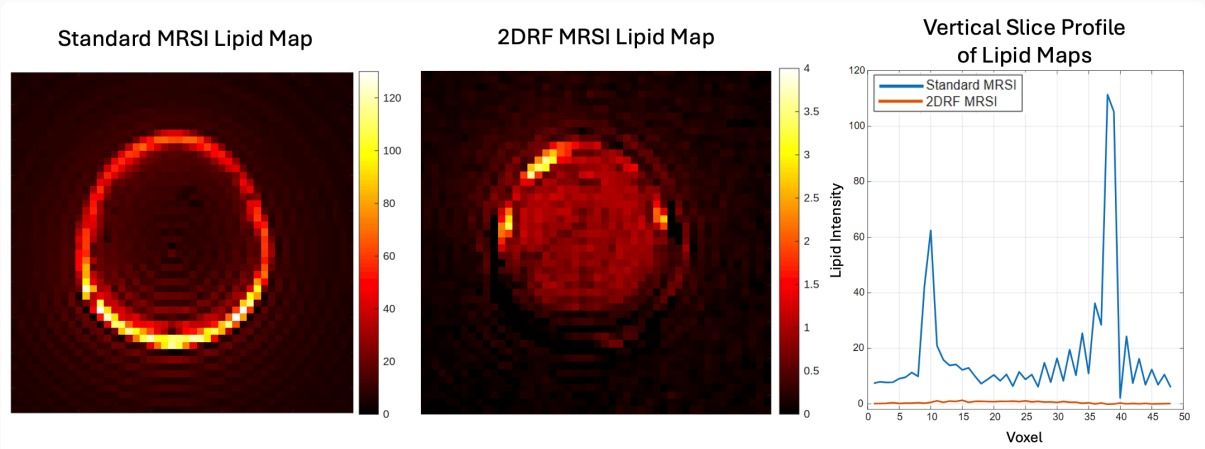

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Figure 3: *A comparison of the lipid signal intensity integrated spatially for the standard MRSI excitation and 2DRF MRSI excitation. The standard MRSI lipid maps shows lipid excitation in the skin and adipose tissue as expected, however large lipid signals are seen within the brain. The 2DRF MRSI lipid map shows a massive reduction in lipid signal, with the intensity scale renormalized. A vertical slice profile was taken for both images and compared on the far right demonstrating lipid signal suppression*

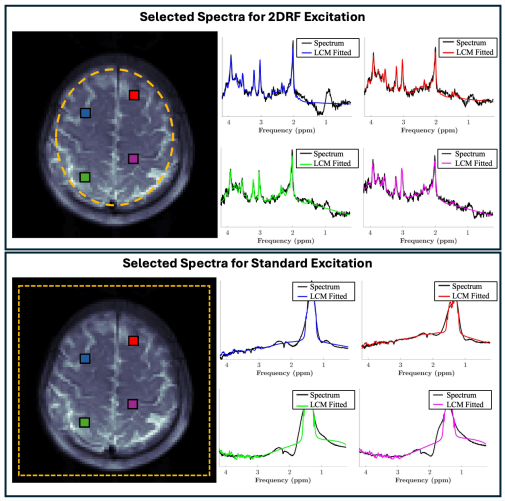

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Figure 4: *Selected spectra for both standard excitation and 2DRF excitation. The standard excitation has massive lipid contamination in each voxel, while the 2DRF excitation reduces the extracranial lipid contamination, uncovering the underlying metabolites and macromolecule spectra. The orange dashed line represents the approximate excitation profile for each experiment. The improved spectral quality with 2DRF excitation demonstrate its advantage for localized MRSI in regions near lipid-rich boundaries*

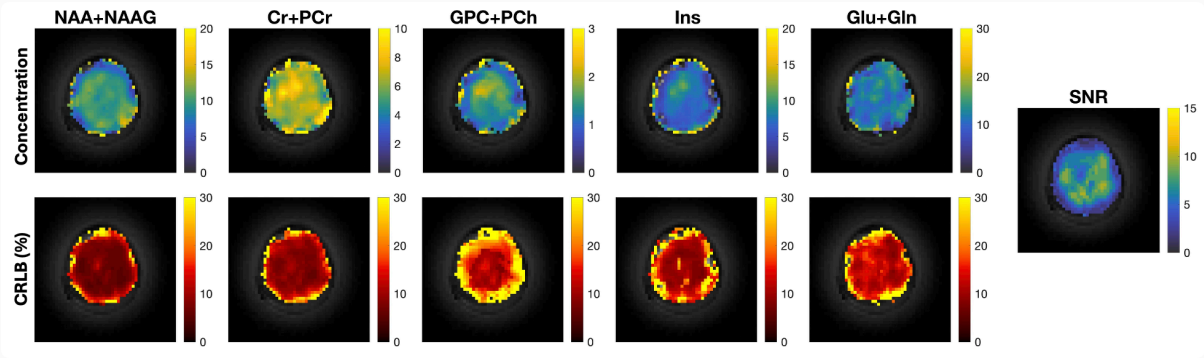

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Figure 5: *Representative in vivo metabolic maps using 2DRF excitation. Concentration maps show spatial distributions of selected metabolites along with corresponding SNR map. The bottom row displays the Cramér–Rao lower bound (CRLB) estimates for each metabolite, reflecting the reliability of the fitted concentrations. The CRLB scores are high in the cortical regions of the brain where the 2DRF excitation profile transitions to zero as expected.*