Multivoxel Proton Magnetic Resonance Spectroscopy for Non-Invasive Thermometry: Improvements in Spectral Quality using semiLASER with GRE Shim

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Target Audience: Researchers and clinicians interested in magnetic resonance spectroscopy-based methods for non-invasive thermometry.

Purpose: Multi-voxel magnetic resonance spectroscopy (MRS), or chemical shift imaging (CSI), is a promising technique for non-invasive *in-vivo* brain thermometry. Quantitative brain temperature measurements are currently costly and highly invasive, and brain temperature regulation remains controversial. MRS-based thermometry utilizes the temperature-dependent ^{1}H chemical shift difference between water and *N*-acetylaspartate (NAA).[1] Current CSI imaging commonly uses a double spin-echo point-resolved spectroscopy (PRESS) sequence that suffers from poor spatial resolution and chemical shift artifacts due to the use of slice selective RF pulses. Additionally, the shim is a critical determinant of spectral quality and subsequently influences all aspects of CSI quantification. Recently, the semiLASER sequence has been proposed to improve upon the PRESS sequence using adiabatic slice selective refocusing pulses for accurate voxel localization and a sharp excitation profile[2]. In addition, a GRE Shim technique has been shown to improve the spectral quality of single-voxel spectroscopy.[3] Our goal was to demonstrate the utility of CSI for thermometry applications using an improved spectroscopic acquisition protocol: a semiLASER spectroscopy sequence with GRE Shim. We compared spectral quality and calculated temperature maps acquired *in vitro* and *in vivo* with PRESS and semiLASER sequences using both Siemens Advanced Shimming (SAS), a vendor-supplied automated shimming protocol, and the GRE Shim protocol.

Methods: All measurements were acquired on a 3.0 T Siemens Magnetom TRIO scanner (Siemens Medical Solutions, Erlangen, Germany). A 3D localizer image (TR = 8.6 ms; TE = 4 ms; flip angle = 20°; 1 x 1 x 7 mm^3 resolution) was used to place the CSI grid. Both PRESS and semiLASER sequences using identical parameters (TR = 1700 ms; TE = 35 ms; 10 x 10 x 15 mm^3 voxel size; 1024 data points; 3 averages) were used to acquire a 16x16 voxel acquisition matrix with an 8x8 voxel region of interest. The SAS shim technique uses a 3D dual-echo steady-state (DESS) gradient-echo sequence that acquires two signals within the same TR period: FISP and PSIF acquisitions. After eddy-current correction, a 3D field map was generated from the two echoes for the calculation of the shim currents. In contrast, for GRE Shim a field map was generated from a single-slab two-echo 3D GRE acquisition performed with two in-phase TEs for fat and water.[4] Shim currents to improve B_0 homogeneity were calculated from the field map. PRESS and semiLASER acquisitions were performed using SAS and then were repeated using GRE Shim. CSI data was acquired on a General Electric (GE) MRS phantom (GE, #2152220) and from 3 healthy volunteers in the subcortical region of the brain. Spectra were analyzed with the linear combination model program (LCModel, Version 6.3-1H).[5] Spectral quality was quantified from the Cramér-Rao Lower Bounds (CRLB) values for the NAA peak. The shim performance was determined from the full width half maximum (FWHM) of the water peak and T2* values. A paired t-test was used to compare spectroscopy sequences and shimming protocols. Temperature was calculated using previously reported *in vitro*[1] and *in vivo*[6] equations. MR-based thermometry equations are derived from the temperature-dependent changes in the ^{1}H chemical shift of water relative to the temperature-independent ^{1}H chemical shift of NAA.

Results: Temperature maps calculated using different combinations of spectroscopy and shimming protocols acquired *in vitro* on an MRS phantom are shown in Figure 1. A representative *in vivo* temperature map is presented in Figure 2. Fitted FWHM line widths and T2* values were used to quantitatively evaluate shimming. For both *in vitro* and *in vivo* data, a narrowing of the line width and a longer T2* value was observed when using GRE Shim compared with SAS. Comparing the PRESS sequence using SAS, the current clinical spectroscopy standard, with our presented method using a semiLASER sequence with GRE Shim, we observed a significant increase *in vivo* in the T2* value (PRESS with SAS: 25.7 ± 0.6 ms; semiLASER with GRE Shim: 30.7 ± 0.6 ms; $p<0.05$) and narrowing of the line width (PRESS with SAS: 24.3 ± 1.5 Hz; semiLASER with GRE Shim: 20.3 ± 1.3 Hz; $p<0.05$). We observed a significant improvement in the *in vivo* spectral quality with GRE Shim, measured by a decrease in CRLB values for NAA, for both the PRESS sequence (SAS: 3.7 ± 0.7%; GRE Shim: 3.4 ± 0.7%; $p<0.001$) and the semiLASER sequence (SAS: 3.3 ± 0.6%; GRE Shim: 3.2 ± 0.4%; $p<0.01$). We also observed a decrease in CRLB values when comparing the standard PRESS using SAS and the semiLASER with GRE Shim ($p<0.001$).

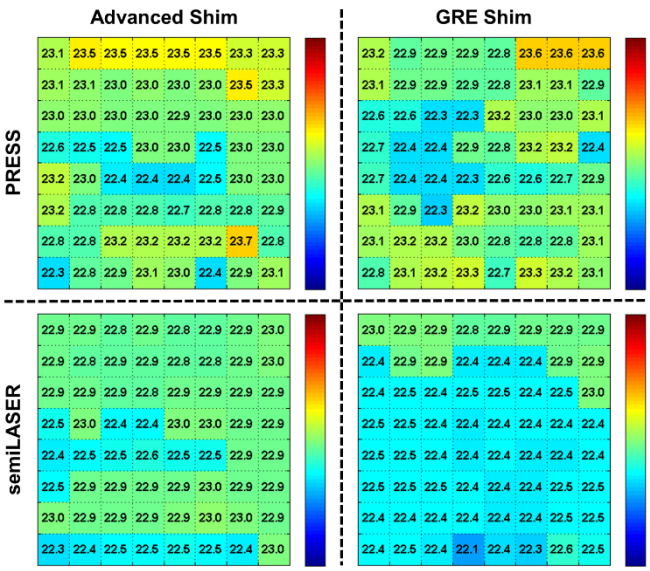

Figure 1. *In vitro* temperature maps of an MRS phantom. CSI data was acquired with either PRESS or semiLASER sequences using Siemens Advanced Shim or GRE Shim. Temperature scale ranges from 21-25° C.

Discussion and Conclusions: We observed that GRE Shim provided a significant improvement in spectral quality when applied to both standard PRESS and semiLASER sequences. *In vitro* temperature measurements acquired from a phantom should be relatively uniform. From the temperature maps, it is evident that the *in vitro* temperature map acquired with semiLASER and GRE Shim is the most homogenous likely due to a more uniform B_0 field produced with GRE Shim (Figure 1). The *in vivo* temperature map of the subcortical brain region of a volunteer demonstrates the utility of CSI for thermometry (Figure 2). We expect that the improved spectral quality and volume localization will be especially useful for thermometry applications resulting in more accurate and reproducible brain temperature measurements. Additionally, literature reports and preliminary results also suggest that performing an eddy-current correction further improves the accuracy of *in vivo* temperature maps and is an ongoing area of investigation.[7] The advanced methods for localization of the CSI grid with the semiLASER sequence combined with the GRE Shim protocol for better B_0 homogeneity are beneficial for thermometry in addition to other applications of CSI.

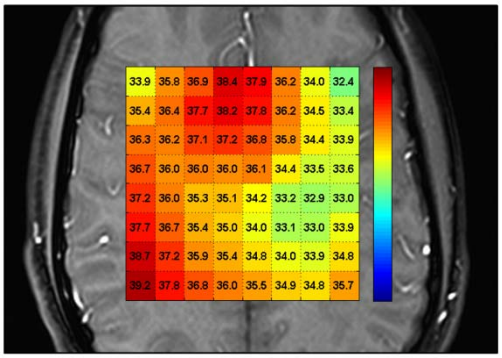

Figure 2. Representative *in vivo* temperature map of a subcortical brain region calculated with MRS-based thermometry using a semiLASER sequence with GRE Shim. Temperature scale ranges from 25-40° C.

References:

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