Fast low-SAR B0-mapping along projections at high field using two-dimensional RF pulses

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Target audience: preclinical/clinical researchers interested in fast and/or low SAR localized shimming techniques at high field

Purpose: High resolution MR spectroscopy (MRS) benefits from the use of higher field-strength through the broader spectral range of metabolite peaks as well as an increase in signal magnitude. At 7T, conventional static field (B_0) mapping techniques along projections (FASTMAP, FASTESTMAP) suffer from elevated Specific Absorption Rates (SAR), forcing the use of long acquisition times (TA). In this context, the objectives of this study are **1.** to design a low SAR two-dimensional radio-frequency (2D-RF) pulse to replace the series of adiabatic pulses needed for pencil selection in FASTMAP and **2.** to compare shimming durations and performances between the two techniques.

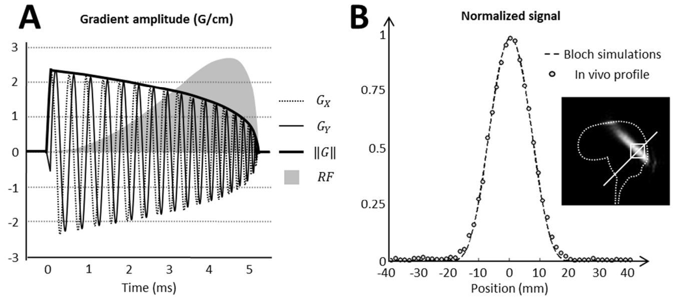

Figure 1. A Spiral gradient waveform and RF shape (a.u.) for pencil excitation and **B.** corresponding simulated and in vivo profile in the occipital lobe (ZY orientation)

Methods: Based on a spiral gradient trajectory[1], a 2D-RF pulse was designed in the small tip angle (STA) regime to meet the sequence specifications and hardware constraints (Siemens 7T/68 cm head scanner - Siemens Healthcare, Erlangen, Germany). TR, TE and FA were adjusted to minimize TA while maintaining an MR signal level equal to that of the adiabatic technique. The relative SAR (rSAR) value between a single 2D-RF pulse at Ernst angle and the series of adiabatic pulses (BIR 45°+ 4x HS8 180°) was computed. The 2D spatial profile was simulated using Bloch Simulations and characterized in vivo (occipital lobe) with a 3D-GE sequence (TR/TE=500/5ms, FOV 200x200x192 mm^2, matrix size 200x200x32). 2D-RF localized shimming was performed in an automatic iterative fashion (8 steps with increasing phase evolution time, total shimming duration 42 s) in 6 Volumes of Interest (N=7, VOI: occipital lobe, frontal white matter, posterior cingulate, putamen, cerebellum, substantia nigra). Shimming quality was assessed using the full width at half maximum of the water peak $FWHM_{H2O}$ obtained after Fourier transformation and phase correction of the FID obtained with a STEAM sequence (TR/TE = 4000/15 ms, SW = 2000 Hz, 4096 points, see VOI size in Table 1), and compared to MRS literature at 7T[2]. The good quality of the spectra acquired after 2D-RF localized shimming is illustrated by a proton spectrum acquired with a semi-adiabatic SPECIAL localization sequence (TR/TE = 7500/12 ms, BW = 4000 Hz, 2048 points, RF pulse frequency offset = 2.3 ppm, NA = 32, TA = 4 min).

Results: For a 1.4 cm-diameter cylinder, spiral gradients with reasonable durations could be designed (5.17 ms, Fig. 1A), leading to accurate and reliable in vivo 2D spatial profiles (Fig. 1B, optimized TR/FA 500 ms/25°) and very little energy deposition (rSAR = 0.1%). $FWHM_{H2O}$ results on healthy volunteers (Table 1) show in 5 ROIs no significant difference ($P > 0.5$) between the spectroscopic linewidths obtained with the adiabatic (TA = 4 min) and the new low-SAR and time-efficient FASTMAP sequence (TA = 42 s). $FWHM_{H2O}$ obtained in the cerebellum were even found slightly narrower in our study. Using LCModel, a large number of brain metabolites (16) can be quantified with precision in the spectra obtained after 2D-RF localized shimming. The quality of the spectrum and fitting is characterized by efficient water suppression, absence of lipid contamination and very little residual fitting and flat spline baseline (Fig. 2).

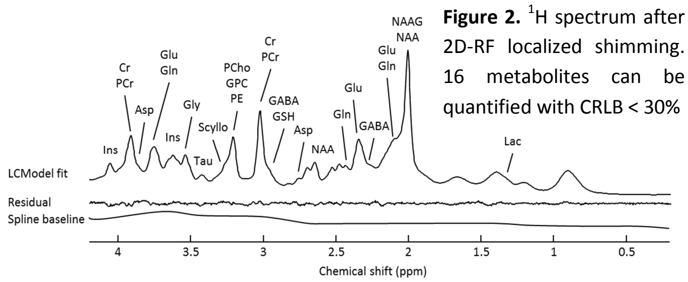

Figure 2. ^{1}H spectrum after 2D-RF localized shimming. 16 metabolites can be quantified with CRLB < 30%

Discussion and Conclusion: The SAR can be reduced by three orders of magnitude and the acquisition time accelerated six times without impact on the shimming performances or quality of the resulting spectra. Using only local B_1 information (i.e. calibration), no parallel transmission / RF shimming was needed to efficiently shim B_0 in each VOI in 42 s. Simply designed short multidimensional pulses can be used to unleash the full potential of FASTESTMAP at high field.

References: 1. Zhao T et al. Proc. ISMRM 2008;p. 1342. 2. Emir UE et al. NMR Biomed 2012;25:152–60. doi: 10.1002/nbm.1727.

VOI	Occipital lobe	Fr. white matter	Posterior cingulate	Putamen	Cerebellum	Substantia nigra
Volume (mL)	8	8	8	2.5	6.25	1
$FWHM_{H2O}$ (Hz)	12.8 ± 0.3	15.5 ± 1.6	11.8 ± 0.5	16.2 ± 0.9	13.8 ± 1.4 *	17.7 ± 0.8
$FWHM_{ref}$ (Hz)	12.7 ± 0.3	15.7 ± 0.8	11.3 ± 0.7	15.9 ± 1.2	14.5 ± 0.6	18.0 ± 1.0

Table 1. Water spectral linewidths obtained after 2D-RF ($FWHM_{H2O}$) and conventional localized shimming from Emir et al.[2] ($FWHM_{ref}$). * indicates that the two distributions are significantly different ($P < 0.05$).