Improved Spectral Quality Through Enhanced Shimming on a Clinical Platform at 3T and 7T

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Introduction Increased spectral resolution and signal-to-noise ratio (SNR) and additional metabolite information not available at B_0 = 1.5T are some of the benefits of magnetic resonance spectroscopy (MRS) at higher fields (≥3T) that enhance its attractiveness as an investigational tool for clinical use. However, to obtain high-quality MR spectra, reliable localized shimming is an essential prerequisite. The fast automatic shimming technique by mapping along projections (FASTMAP) (1) and its descendant FASTESTMAP (2) have been successfully used on experimental high-field systems up to 9.4T (3). Their use on an ultra-high field clinical MRI scanner (≥3T) has not been reported. In this work, FASTMAP and FASTESTMAP were implemented on a clinical platform of a 3T and a 7T system, and in vivo proton spectra of the human brain were acquired, and an effect of the improved shimming on the spectra was investigated.

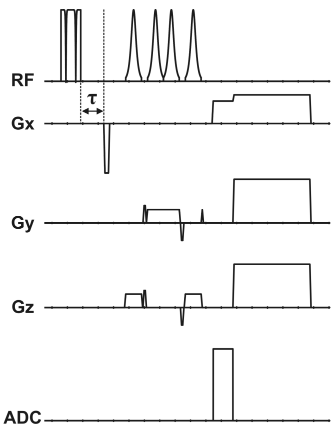

Fig. 1. Fully adiabatic FASTMAP pulse sequence using a BIR-4 and two pairs of hyperbolic secant pulses.

Methods Scans were performed on a 3T Trio and a 7T head only system (Siemens Medical Solutions, Erlangen, Germany). Both techniques were implemented as a SE-based sequence using only adiabatic rf-pulses to reduce sensitivity towards B_1 inhomogeneities (2). The pulse sequence diagram for FASTMAP is shown in Fig. 1. For FASTESTMAP, the delay τ is replaced by an EPI-like readout train (2). For shimming of a volume of interest (VOI), 1D projections of dimensions 300x15x15 mm^3 through the center of the VOI were acquired with and without the delay τ or using an echo train of six echoes to measure the B_0 distribution along up to six different orientations. Scan parameters were: TR/TE=5000/31(5000/34 at 7T), vector size=256, bandwidth (BW)=50 kHz, and τ=2-10 ms. After Gaussian filtering, resulting data were analyzed to determine the optimum settings for all first- and second-order shim coils. All processing steps were incorporated in the routine scanner software. The water linewidth was measured to assess the achieved field homogeneity. Typically, 3-5 iterations were used to complete the shimming procedure. Finally, single voxel spectroscopy (SVS) data were acquired for various human brain regions using the spin echo full intensity acquired localized (SPECIAL) technique (4).

Results After shimming with FASTMAP/FASTESTMAP, water linewidths (LW_{H20}) ~ 6 Hz were obtained at 3T in homogeneous gray matter (GM) and white matter (WM) regions. In the hippocampus, which is known as a region difficult to shim, linewidths ~ 8 Hz were achieved, even though some of the shim changes calculated by the FASTMAP method exceeded the available shim strength of some second-order shim coils. However, this compared favorably to the previously achieved linewidth of 13 Hz using a global routine shimming method. At 7T, LW_{H20} ~ 12-14 Hz were obtained in GM and WM, and 18 Hz for the very inhomogeneous region of the substantia nigra. Fig. 2 shows ^{1}H spectra from WM and GM of human volunteers acquired at 3T and 7T. Note that in both spectra the peaks of Glu (Glx), Ins, and Cr are clearly resolved. Metabolite linewidth was estimated as 3 Hz and 9 Hz at the two fields.

Discussion The FASTMAP/FASTESTMAP shimming techniques were successfully implemented and used on a clinical platform of a 3T and a 7T system. The shimming procedure was smooth and could be initially completed in a few minutes. Proton spectra from various brain regions were acquired and showed excellent quality due to the enhanced local field homogeneity resulting from improved shimming. In addition, the techniques allow increased flexibility in designing optimized shim protocols for areas of large B_0 field variations. Finally, the availability of improved shimming methods on a clinical platform will further strengthen the clinical utility of MRS and MRI techniques that require enhanced B_0 field homogeneity.

References and Acknowledgements (1) R. Gruetter, MRM, 29(6), 804-811. 1993; (2) R. Gruetter, MRM, 43(2), 319-323. 2000; (3) I. Tkac et al., MRM, 52(3), 478-484, 2005; (4) V. Mlynarik et al., MRM, 56(5), 965-970, 2006.
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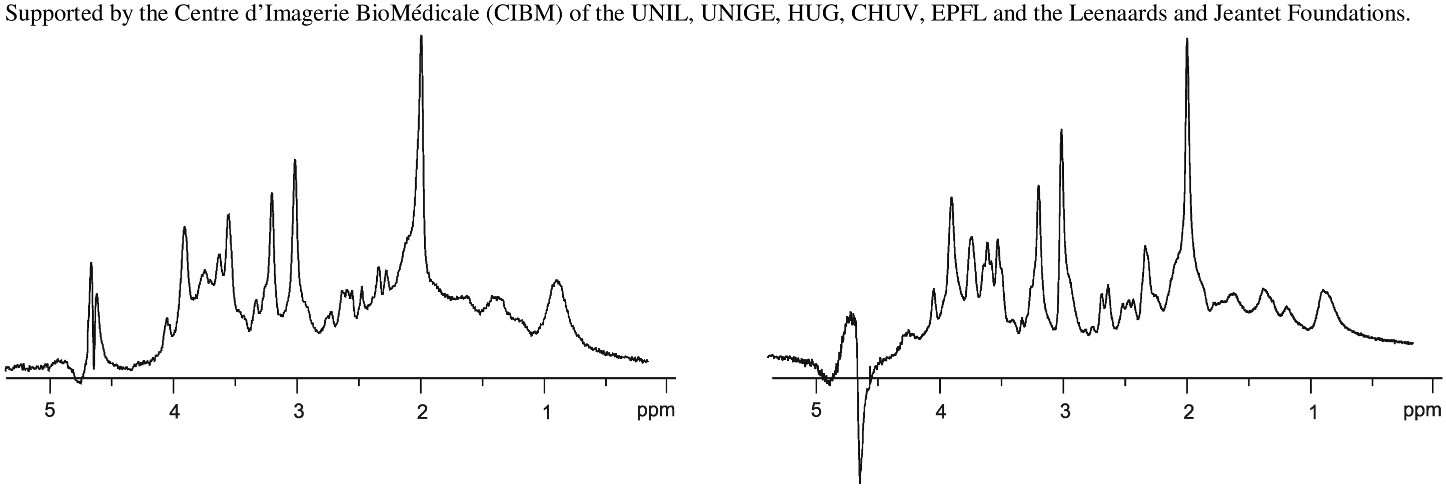

Fig. 2. ^{1}H spectra from human volunteers acquired with the SPECIAL sequence after shimming with the FAST(EST)MAP techniques. *Left*: 3T, TEM volume coil, VOI=20x20x20 mm^3 in parietal WM, TR/TE=2000/6, BW=2kHz, 256 scans; *Right*: 7T, surface coil, VOI=30x15x30 mm^3 in occipital GM, TR/TE=4000/5.7, BW=4kHz, 64 scans. Data processing consisted of zero-filling up to 16-k data points, minimal Gaussian weighting of the FID, Fourier transformation, and phase correction. Note the high quality of the spectra achieved through enhanced localized shimming.