Improved 3D MRSI on rat brain *in situ* with multicoil shimming

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Introduction

Focused-beam microwave irradiation (FBMI) has been shown to rapidly and stably halt *in vivo* metabolism, thereby opening up the possibility of high-resolution and high-sensitivity measurement *in situ* [1]. By combining FBMI and ^{13}C-labeled substrate infusion it was recently shown that 3D metabolic flux maps could be generated [2]. Even though the 3D MR spectroscopic imaging (MRSI) generates a large amount of data (e.g.,> 3200 brain voxels of 1.0 µL/voxel) per animal, only about 33% of that data is of acceptable spectroscopic quality. Insufficient magnetic field homogeneity due to the limited number of available spherical harmonics (SH) shim coils is the primary reason for the high data rejection rate. Shimming based on the multi-coil (MC) principle has been shown to provide greatly improved magnetic field homogeneity on rodent brain when compared to SH shims [3]. Here MC shimming was applied to the brains of rats euthanized by FBMI. In addition to B_0 and linewidth maps the improved performance of MC shimming is demonstrated on 3D GABA-edited MRSI.

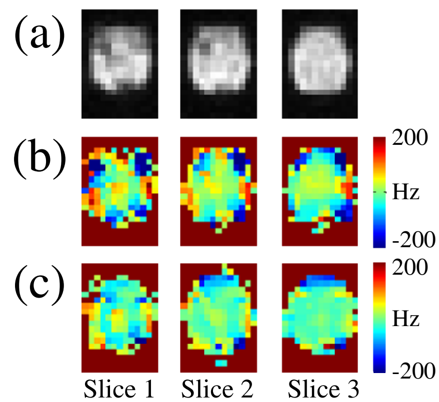

Figure 1. (a) Water MRSI intensity maps with corresponding B_0 images acquired with different shim approaches: (b) third-order spherical harmonic shimming and (c) multicoil shimming.

Methods

Animal Five male Sprague-Dawley rats were sacrificed by FBMI (4.5 kW, 1.1 s). After removal of extracranial tissues, the intact brain and skull were immersed in Fluorinert FC-43 (3M, St. Paul, MN) to minimize magnetic susceptibility differences.

MR measurement All experiments were performed on an actively-shielded 11.74 T horizontal magnet interfaced to a DirectDrive spectrometer (Agilent, Santa Clara, CA, USA). Transmission and reception were accomplished with a homebuilt coil composed of a ^{1}H 5-turn solenoid coil and a ^{13}C Helmholtz coil. A 48-channel MC setup (15 turns, +/- 1A per coil) was placed around the RF coil assembly. B_0 maps were acquired with a gradient echo sequence (TR 1200 ms, TE 2.5 ms) with four additional delays (0, 0.33, 1.0 and 3.0 ms) to acquire phase information necessary for calculating the shims terms. Subsequently, 3D MRI (TR 500 ms, TE 25 ms, 190 x 190 x 190 µm), water MRSI (TR 1500 ms, TE 20 ms, 1 average, 1.5 µL nominal voxels) with two static shimming approaches, and GABA-edited MRSI with a *J*-difference editing technique (TR 3000 ms, TE 68 ms, 8 averages, 1.5 µL nominal voxels) were acquired.

3D MRSI pulse sequence After suppressing the water signal with VAPOR, the volume selection in the z direction was achieved with a 0.5 ms SLR excitation pulse, followed by a pair of adiabatic full-passage (AFP) pulses (1 ms) to select a volume in the y direction. For the *J*-difference editing measurement, Gaussian-shaped editing pulses (10 ms) were applied at the frequency of the GABA-H3 resonance in the first scan and at a frequency mirrored relative to the water signal in the second scan. In 3D MRSI measurements, a spherical center-out phase-encoding scheme was used. Temporal drift of the main magnetic field was monitored and corrected using navigator signals acquired every 5 min.

Comparison of shimming performance The total number of voxels meeting three criteria (minimum amplitude > 7% of maximum amplitude, maximum B_0 shift < 30 Hz, maximum linewidth < 30 Hz) were calculated for water MRSI data sets acquired with SH shims and MC shims.

	Inclusion (%)	Delta B_0 (Hz)	Linewidth (Hz)
SH	33 ± 3	18 ± 4	29 ± 1
MC	44 ± 5	8 ± 2	23 ± 1

Table 1. Comparison of quantitative values acquired with spherical harmonic shims (SH) and multicoil shims (MC). The values were expressed as mean ± standard deviations

Results

Figure 1 shows (a) water MRSI intensity images and B_0 images acquired with (b) third-order SH shims and (c) MC shims, illustrating improvements of the magnetic field homogeneity with the latter approach. The increased B_0 homogeneity by MC shimming led to higher data inclusion rates, lower standard deviations of B_0 and average linewidth, as summarized in Table 1. Representative spectra acquired with 3D MRSI with the *J*-difference editing technique are shown in Fig. 2, demonstrating reliable detection of GABA at 3.01 ppm throughout brain regions.

Discussion

Here we have shown that MC shimming outperforms third-order SH shimming on the rat brain after FBMI euthanasia, similarly to earlier reported improvements of MC shimming *in vivo* [3]. One remaining source of magnetic field inhomogeneity pertains to the microsized air bubbles that can be generated in the brain during FBMI. As these are high-amplitude disturbances over a limited spatial region they are beyond the capabilities of existing shimming methods. Nevertheless, MC shimming provided consistent magnetic field homogeneity improvements, allowing for the acquisition and processing of a significantly larger fraction of the ^{1}H spectral data set. The presented technology should open the way to generate high-resolution 3D metabolite and metabolic flux maps across the entire rat brain.

References

[1] de Graaf RA et al. J. Neurochem. 2009; 109: 494-501. [2] Hong S et al Proc. Intl. Soc. Mag. Reson. Med. 2013; 21: 862. [3] Juchem C et al. Magn. Reson. Med. 2011; 66: 893-900.

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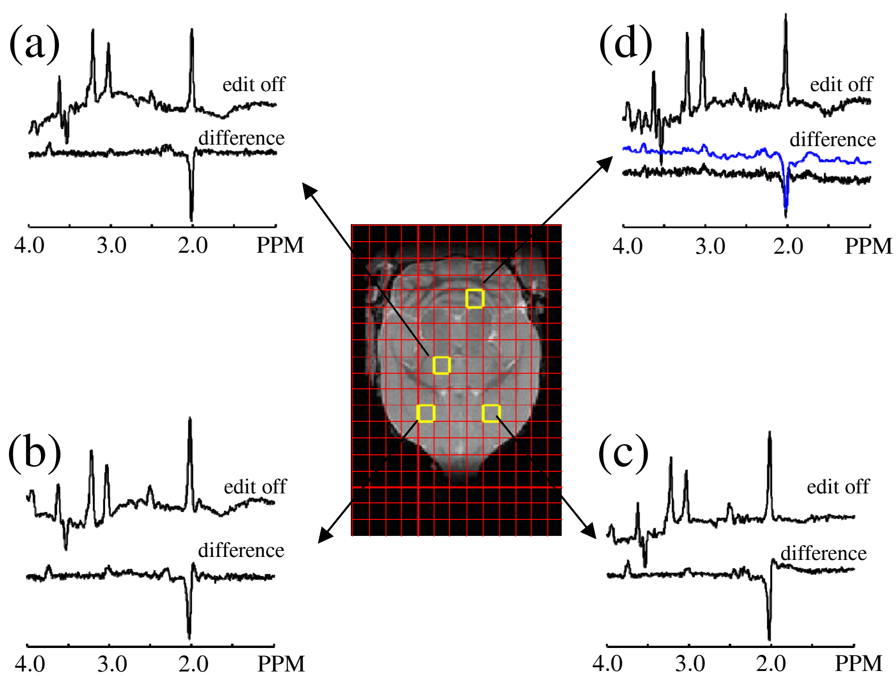

Figure 2. *In situ* 3D MRSI with the *J*-difference editing technique for detecting the H4 signal of GABA at 3.01 ppm. Representative spectra from (a) thalamus, (b, c) caudate putamen and (d) cerebellum. No apodization was applied in all spectra shown (black). The difference spectrum in (d) is shown also with 10 Hz exponential broadening (blue) for modest SNR enhancement.