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

Sungtak Hong1, Christoph Juchem1, Peter B. Brown1, Kevin L. Behar2,3, and Robin A. de Graaf1

1MR Research Center (MRRC), Yale University School of Medicine, New Haven, Connecticut, United States, 2Psychiatry, Yale University School of Medicine, New Haven, Connecticut, United States

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 13C-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) shims 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 B0 and linewidth maps the improved performance of MC shimming is demonstrated on 3D GABA-edited MRSI.

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 11.7T horizontal magnet interfaced to a DirectDrive spectrometer (Agilent, Santa Clara, CA, USA). Transmission and reception were accomplished with a homebuilt coil composed of a 1H 5-turn solenoid coil and a 13C Helmholtz coil. A 48-channel MC setup (15 turns, +/-1A per coil) was placed around the RF coil assembly. B0 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 B0 shift < 30 Hz, maximum linewidth < 30 Hz) were calculated for water MRSI data sets acquired with SH shims and MC shims.

Results
Figure 1 shows (a) water MRSI intensity maps and B0 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 B0 homogeneity by MC shimming led to higher data inclusion rates, lower standard deviations of B0 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 1H 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

This research was supported by NIH grants R01-MH095104, R01-EB014861 and P30-NS052519.