High-resolution LASER-localized chemical shift imaging in the rat brain at 9.4 T

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Chemical shift imaging (CSI) simultaneously provides spatial and spectral information. However achieving good spectral quality and good spatial resolution while retaining the information from J-coupled resonances is challenging. The goal of the present work was to achieve high-resolution CSI of a large number of metabolites, including J-coupled metabolites in the rat brain. 2D-CSI maps were obtained in the rat brain at 9.4 Tesla with 0.5×0.5 mm^2 nominal in-plane resolution using short-TE LASER prelocalization and LCModel analysis with simulated basis sets.

Materials and Methods

NMR acquisition

Male Sprague-Dawley rats were anesthetized with isoflurane (~1.5 %) in O_2/N_2O (30%/70%). Experiments were conducted on a horizontal 9.4 T/31 cm Varian system equipped with a gradient coil reaching 450 mT/m in 200 µs. A surface quadrature coil positioned on the top of the head was used for radiofrequency emission and reception. A 12×7×3 mm^3 LASER [1] voxel (TE= 20 ms, TR= 2 s) was positioned in a region of the brain including deep brain structures and cortical layers (fig. 1). 1st and 2nd order shimming was performed within this voxel using Fastmap, allowing to reach a ~15 Hz full width at half maximum (FWHM) on the water resonance. Water signal was suppressed using an 8-pulse VAPOR module. CSI localization within the pre-localized volume was achieved using a ~1 ms gradient encoding positioned just before the acquisition. A 26×16 encoding was performed within the coronal plane, the field of view (FOV) being 13×8 mm^2, resulting in a 0.75 µL nominal voxel size. The sampling of *k*-space was weighted by a Hamming function to obtain an optimal spatial response function (SRF) with reduced cross-contamination (fig. 2). A total of 2992 scans were acquired, corresponding to a ~100 minutes CSI acquisition.

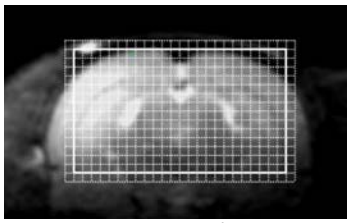

Fig. 1: The 12×7×3 mm^3 LASER pre-localization voxel (continuous lines) and the 26×16 2D-CSI matrix (FOV=13×8 mm^2) (dashed lines).

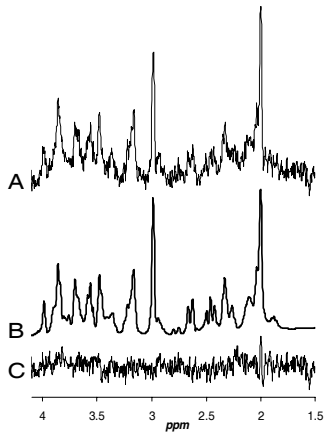

Fig. 3: (A) Typical spectrum obtained in an individual 3 µL CSI voxel positioned in the central region of the LASER volume (SNR~20, lb=3 Hz). (B) LCModel fit. (C) Residuals.

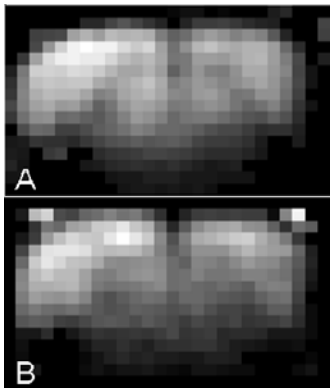

Fig. 4: Metabolic maps (no spatial filtering) generated from LCModel results. (A) NAA. (B) Glutamate. Only voxels with CRLB<15% are displayed.

Data analysis

A fully automated, user-friendly routine package was developed in Matlab to reconstruct CSI data-sets, to perform LCModel analysis [2], and to display LCModel results as metabolic maps. More precisely, reconstructed CSI spectra were analyzed using a basis-set simulated with home-made Matlab programs [3] based on the numerical calculation of the density matrix during the LASER sequence, for 19 metabolites including alanine, aspartate, choline, creatine, GABA, glucose, glutamate, glutamine, inositol, NAA and taurine.

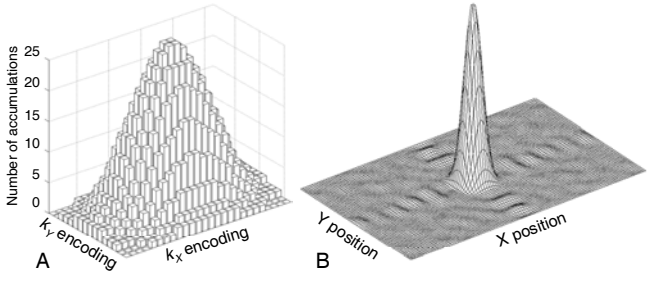

Fig. 2: (A) Weighted acquisition scheme (total 2992 scans). (B) Corresponding spatial response function.

Results and Discussion

Localization efficiency

In addition to selecting a slice along *Z*, the LASER pre-localization was used to limit spectral contamination from lipid signal originating from the scalp and to reduce the FOV in the coronal (*XY*) plane, so that Hamming-weighted acquisition could be performed, yielding a favorable SRF with reduced bleeding (fig. 2). Consequently, even in CSI voxels close to the skull, this lipid contamination remained small. The nominal in-plane resolution was 0.5×0.5 mm^2, however the actual SRF associated with Hamming-weighting resulted in to a two-fold increase of the effective voxel width as compared to a uniform *k*-space sampling, leading to a ~1×1 mm^2 effective in-plane resolution and a ~3 µL effective voxel volume. This is among the highest effective (i.e. including actual SRF) CSI resolution reported in the rodent brain [4,5,6].

Spectral quality

A typical spectrum from a CSI voxel in the central region of the LASER volume is shown on fig. 3. The FWHM on metabolites was typically less than 10 Hz, except in the very vicinity of the upper edge of the LASER voxel where the close air-tissue interface degraded B_0 homogeneity. The SNR on individual voxels ranged from ~8 in the deep regions of the brain to ~25 in the cortical layers close to the coil. In the low SNR voxels, LCModel was able to estimate concentrations with Cramer-Rao lower bounds (CRLB) typically less than 15-20% for several metabolites including NAA, creatine, glutamate, glutamine, taurine, inositol and GABA In the more cortical regions of the brain the CRLB fell down to less than 5% for these metabolites (10% for glutamine and GABA), demonstrating the good spectral quality. Given the high information content of each voxel, frequency shift due to B_0 variations could be directly assessed by LCModel and hence did not require B_0 map or water CSI acquisition for prior correction.

Metabolic maps

Metabolic maps (fig. 4) were generated from LCModel results, the intensity for each pixel being the LCModel concentration estimated for that given pixel, for any specified metabolite. Such maps are straightforward visual tools for inspecting CSI data-sets, with the advantage over classical CSI images (where a pixel value is the signal integral over a given chemical shift range [7]) that here the intensity is directly related to a metabolic content (weighted by the coil sensitivity). Note that the high spatial resolution makes it possible to distinguish structures such as ventricles (darker areas) on the metabolic maps.

Conclusion

Using short echo-time LASER CSI combined with LCModel analysis, high resolution metabolic maps (26×16 matrix, 3 µL effective voxel size) were obtained in the rat brain at 9.4 T. These new developments will be useful to study regional metabolic alterations in rodent models.

Acknowledgments

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