Ultrafast high-resolution spectroscopy with asymmetrical gradients under inhomogeneous magnetic fields

Zhiliang Wei[1], Liangjie Lin[1], Jian Yang[1], Yanqin Lin[1], and Zhong Chen[1]

[1]*Department of Electronic Science, Xiamen University, Xiamen, Fujian, China*

Target audience

Those who are engaged or interested in the field of localized magnetic resonance spectroscopy (MRS) and expect an ultrafast acquisition of high-resolution localized magnetic resonance spectra under inhomogeneous magnetic fields are target readers.

Purpose

In vivo localized two-dimensional (2D) MRS, which is employed to alleviate the problem of low spectral resolution of one-dimensional (1D) by spreading resonances over a 2D plane, arguably constitutes one of important techniques for noninvasive analysis of tissue metabolites [1]. However, the applications of conventional 2D spectroscopy are restrained due to the following two aspects: first, long acquisition time is evitable to ensure the resolution due to the long magnetization recovery time between the repeated excitations with different indirect dimension evolution times; second, high-resolution spectra cannot be obtained under inhomogeneous magnetic fields. Thereby, a pulse sequence addressed as asymmetrical gradient based single-scan spatiotemporal localized correlated spectroscopy (AGE-SEL-COSY), within which the encoding and decoding is carried out under asymmetry gradient, was performed to obtain high-resolution 2D correlated spectra under inhomogeneous magnetic fields within a single scan in less than one second.

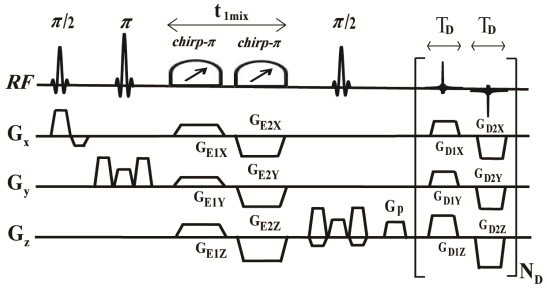

Fig. 1 sequence of asymmetrical gradient based spatiotemporal localized 2D correlated spectroscopy

Method

Spatiotemporal encoding technique proposed by Frydman et al constitutes a solution to the time expense of conventional multi-dimensional experiments by compressing the 2D experiment into a single-scan [2]. Adiabatic chirp π pulses are employed for encoding and an echo planar spectroscopic imaging module is utilized to repeatedly read out the encoded information. In original spatiotemporal encoding localized 2D correlated spectroscopy (SLCOSY) [3], the encoding and decoding module are implemented in the presence of bipolar gradients with the same intensity. The direct dimension of SLCOSY is immune to linear field inhomogeneity along the Z direction by shifting the echo positions in k-space during data post-processing. This manipulation may be difficult when dealing with large linear inhomogeneity along Z axis or just fail when dealing with inhomogeneity along X and Y axes. Therefore, AGE-SEL-COSY (Fig.1) sequence is developed, within which the encoding/decoding gradients are set asymmetrically and additional asymmetrical gradients along X and Y axes are employed to obtain robustness against linear inhomogeneity along X, Y and Z axes, namely 3D linear inhomogeneity.

All experiments were performed on an 11.7 T Varian NMR System (Varian, Palo Alto, CA) under the temperature of 296 K. The proposed AGE-SEL-COSY was tested on two different types of samples, including chemical solution and biological tissue to demonstrate its performance under inhomogeneity. For comparison, spectra by conventional 2D COSY were required with each costing 35 minutes. The 2D spectra acquired by AGE-SEL-COSY were recorded in a single-scan, costing less than a second. The raw data were saved and processed using home-made software based on MATLAB. All 2D spectra are displayed in magnitude mode.

Results and discussion

The results of experiments on ethyl 3-bromopropionate and propionic acid were demonstrated in Fig. 2. It can be seen that the conventional 2D COSY has better performance under homogeneous field. When dealing with 3D linear inhomogeneity, it broadens obviously along both dimensions from 4.9 Hz and 11.0 Hz to 554.2 Hz and 562.7 Hz in direct and indirect dimensions, respectively. As a comparison, the AGE-SEL-COSY spectra under homogeneous and 3D linear inhomogeneity are almost identical, suggesting its robustness against 3D linear inhomogeneity.

The results of experiments on pig marrow tissue were presented in Fig. 3. From the partial accumulative projections of the 2D spectra, it can be seen that the resolution is improved from 147.4 and 150.0 Hz to 58.2 and 69.0 Hz, respectively, in direct and indirect dimensions. As an additional proof, the cross peaks in Fig. 2(b) are clearer than those in Fig. 2(a), suggesting an easier assignment. The results demonstrate the feasibility of AGE-SEL-COSY to obtain high-resolution 2D spectra in the presence of 3D linear inhomogeneity.

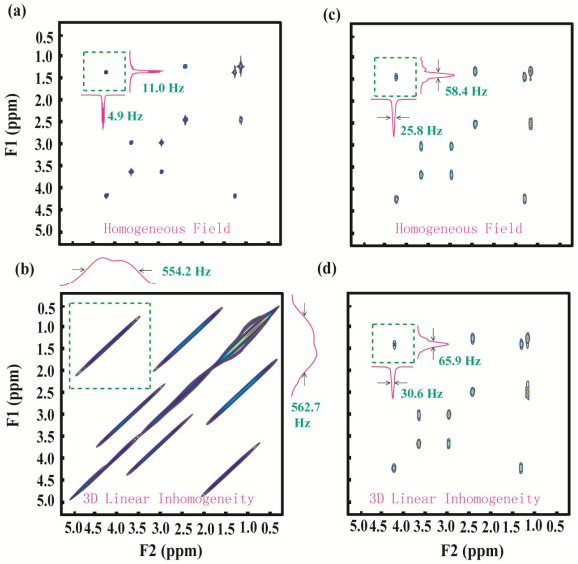

Fig. 2 Spectra of ethyl 3-bromopropionate and propionic acid acquired by conventional 2D COSY (a,b) and AGE-SEL-COSY (c,d).

Conclusion

From the experimental results, AGE-SEL-COSY is capable to perform well under 3D linearly inhomogeneous magnetic fields. Also, it takes only a single-scan to obtain a 2D correlated spectrum, forming an acute comparison to a conventional 2D COSY costing thirty minutes. The single-scan nature of AGE-SEL-COSY can be valuable for alleviating motion artifacts in *in vivo* experiments. Before applications to in-vivo systems, some improvements enhancing the SNR and ironing out the inhomogeneity apart from linear parts can be helpful. The AGE-SEL-COSY offers perspectives to obtain high-resolution correlated spectra of in-vivo systems under inhomogeneous magnetic fields within greatly reduced time.

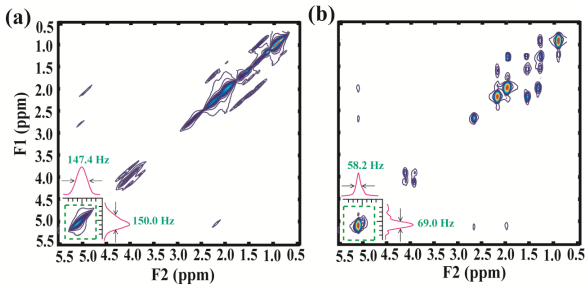

Fig. 3 Spectra of marrow tissue acquired by conventional 2D COSY (a) and AGE-SEL-COSY (b).

Acknowledgments

This work was partially supported by the NNSF of China under Grants 11105114, 11174239 and 11375147, and the Fundamental Research Funds for the Central Universities under Grant 2010121010.

References

[1] M.A. Thomas, et al. Localized two-dimensional shift correlated MR spectroscopy of human brain. Magn. Reson. Med. 58-67 (2001). [2] L. Frydman, et al. The acquisition of multidimensional NMR spectra within a single scan. Proc. Natl. Acad. Sci. 15858-15862 (2002). [3] Y.Q. Lin, et al. Ultrafast localized two-dimensional magnetic resonance correlated spectroscopy via spatially encoded technique. Magn. Reson. Med. DOI 10.1002/mrm.24731 (2013).