Spectral bandwidth considerations for high field volumetric proton echo-planar spectroscopic imaging

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Introduction

Full coverage of the *in vivo* proton brain metabolite spectrum, including downfield resonances, requires a spectral bandwidth of approximately 9 ppm. Spectral bandwidth for *in vivo* echo-planar spectroscopic imaging (EPSI) is limited at higher magnetic field because of limits on gradient strength and gradient slew rate to avoid peripheral nerve stimulation. Conventional EPSI reconstruction involves separation of even and odd readout echoes and makes use of only half the spectral bandwidth. While interlaced Fourier transform (iFT) [1] of even and odd echoes was suggested to exploit the full spectral bandwidth, this method has not been thoroughly analyzed regarding its usefulness for *in vivo* 3D EPSI. Our goal was to develop a robust procedure to overcome limited coverage of spectral bandwidth with 3D EPSI. Limitations of the iFT method are discussed and an alternative, cyclic spectral unwrapping, is proposed, which employs prior knowledge of typical *in vivo* spectral patterns.

Methods

3D EPSI [2] was performed at 4T (Bruker MedSpec) on normal human brain using TR/TE/TI =1780/45/280 ms, with global inversion-recovery for lipid suppression, a FOV of 280x280x180 mm and a matrix of 50x50x18 points. The oscillating readout gradient allowed a full spectral bandwidth of 9.9 ppm with iFT. The iFT algorithm was integrated into the data processing [3]. Prior knowledge about *in vivo* proton resonances was used to alleviate the spectral bandwidth limitation. Given the relatively small voxel size acquired with 3D EPSI, the relatively long TE, and low SNR, downfield resonances are not detectable with 3D EPSI, and the spectral bandwidth requirement can be relaxed to 4.5 ppm. Data can then be acquired with the receiver frequency centered in the upfield region rather than on water. Alternatively, in this study the data was acquired without frequency offset and shifted in the spectral domain during post-processing to unwrap spectral aliasing. To maintain symmetry of the spectral bandwidth around the on-resonant water peak, spectra were zero-filled appropriately in the downfield region.

Results and Discussion

Fig. 1 shows a typical spectrum obtained by iFT reconstruction for the full spectral bandwidth (a) and a reduced width to emphasize details in the metabolite region (b and c). Spectra in Fig. 1b and 1c were phased to present the upfield and downfield region, respectively, in absorption mode. A strong Nyquist artifact is visible in Fig. 1a. Residual aliasing occurs in the downfield region in Fig. 1b and 1c with aliased peaks assigned as "NAA" (6.96 ppm), "Cr" (7.97 ppm), and "Cho" (8.17 ppm). The relative area of the aliased NAA peak is on the order of 10%. The relatively large residual aliasing and Nyquist artifacts are attributed to instrumental imperfections causing the phase relationship between even and odd data to be disturbed, which leads to measurement errors in both, the k-space trajectory as well as the data itself. In Fig. 2 is shown the spectrum from the same voxel as in Fig. 1, however, reconstructed with cyclic unwrapping of aliased spectral components. The spectrum is shown over the entire spectral bandwidth of 9.1 ppm. Spectral zero-filling in the downfield region effectively extended the spectral bandwidth by 4.16 ppm. All spectral components are retrieved and aliasing and Nyquist artifacts are avoided.

Conclusions

Since instrumental instabilities, leading to small but significant phase discontinuities between even and odd readout echoes, cannot entirely be eliminated, the iFT method generally fails to reconstruct *in vivo* proton 3D EPSI spectra without aliasing artifacts. Cyclic spectral unwrapping was shown to allow adequate reconstruction of 3D EPSI data, provided the spectral bandwidth after even-odd echo separation is on the order of 4.5 ppm or above, and permits the use of longer readout gradient lobes of smaller amplitude reducing frequency drift [2] and acoustic noise. Cyclic spectral unwrapping is limited by the requirement that downfield resonances do not give rise to detectable signals. This may not be fulfilled at very short echo times; these, however, are difficult to realize due to problems with increased residual water and lipid signals. In conclusion, in contrast to the error-prone iFT method, cyclic spectral unwrapping is a robust method to overcome limited coverage of spectral bandwidth in 3D EPSI.

References

[1] Metzger G, et al. J. Magn. Reson. 125, 166-170 (1997). [2] Ebel A, et al. Magn. Reson. Med., *in press*. [3] Ebel A, et al. Magn. Reson. Imaging 21, 113-120 (2003).

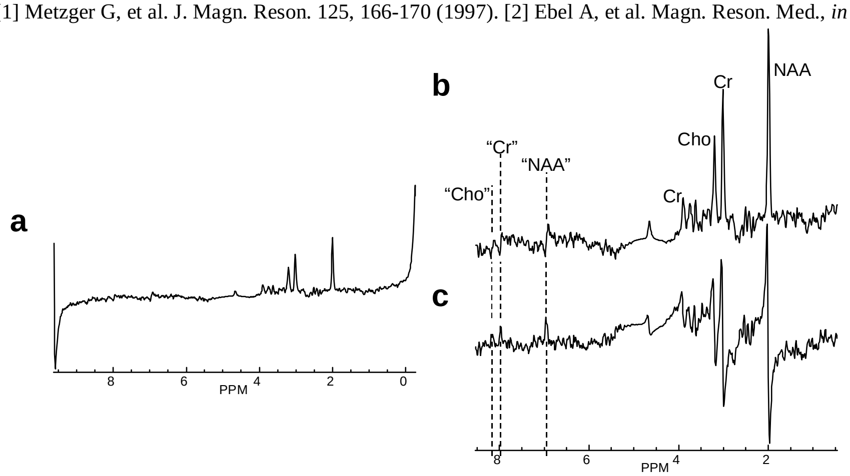

Fig. 1: Spectrum reconstructed with iFT for (a) full and (b and c) reduced spectral width, phased to display the upfield (a,b) and downfield (c) regions, respectively, in absorption mode.

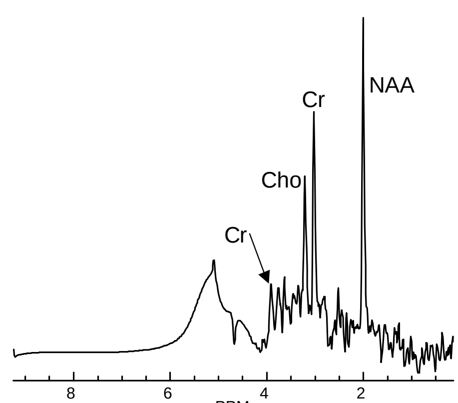

Fig 2: Spectrum from the same voxel as in Fig. 1 but reconstructed with cyclic spectral unwrapping.