Fast Chemical Shift Imaging with Ultra Short Echo Time

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Introduction: Proton chemical shift imaging (CSI) [1] has been extensively used to acquire localized spectra from metabolites in the human brain. But the majority of these *in vivo* ^{1}H CSI studies were performed using long TE (i.e., .144 ms) acquisitions, from which only the signals from N-acetylaspartate (NAA), choline (Cho), and creatine (Cr) containing moieties can be detected. However, other metabolites, such as myo-inositol (myo-Ins) and glutamate show abnormal levels in several neurological diseases but are subject to significant signal loss due to J-coupled phase modulation and fast T2 relaxation rates at long TEs. Conventional CSI is very time consuming because of the large number of PE's during the acquisition. Echo planar Chemical Shift Imaging (EPCSI), a much faster sequence, has been proposed, implemented, and demonstrated over the last two decades [2]. With EPCSI, readouts are not purely spectroscopic but are acquired with a rapidly switching encoding gradient, enabling the acquisition of the both spectral and spatial information in one dimension simultaneously. Phase encoding is only required for the remaining spatial dimension(s). Most implementations of EPCSI have focused on using spin-echo EPCSI readouts in the acquisitions, which results in a minimum TE no smaller than 13ms [3]. Although it is possible to have ultra-short echo time (1ms) with stimulated echo acquisition mode (STEAM) localization [4], but STEAM automatically loses a factor of 2 in sensitivity. To our knowledge, using FID EPCSI (i.e. zero TE EPCSI) to collect metabolic information has not been reported. Here we present FID EPCSI, a fast chemical shift imaging method with no echo to increase signal to noise (SNR) as well as to enable detection of additional metabolites.

Methods: In our FID EPCSI implementation, we use EPCSI gradient readouts immediately following a slice-selective RF pulses to acquire CSI data sets from the human brain. *In vivo* 16x16 EPCSI from single slice was acquired on 3T Philips Achieva scanner (R 1.7.1, Philips Medical Systems, Best, The Netherlands), with 1500ms TR, 2048 gradient echoes (1024 even echoes, 1024 odd echoes), 250mm FOV, and 10mm slice thickness. The delay between the RF pulse and the start of EPCSI readout was 0.5ms. CHESS pulses and outer volume suppression (8 regional suppression technique (REST) slabs) have been used for water and fat suppression before data acquisition. The total data acquisition time for one measurement was 28 seconds. Reconstruction is performed on even and odd echoes by shifting each sampled point to a common temporal origin by using Matlab (Mathworks, Natick, MA, USA). This scheme causes the effective sampling interval for the spectra to be twice the echo time (after reconstruction the effective spectral dwell time = 0.74ms). Additional offline water suppression and Gaussian filter were applied by using 3D*i*CSI, an interactive program under development in our lab [5].

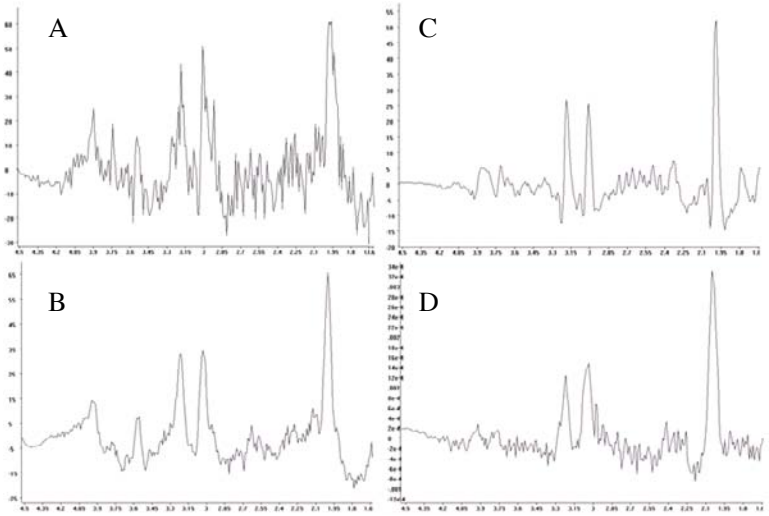
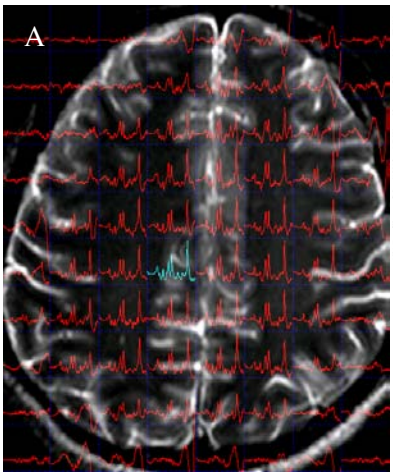


Figure 1: (A) 16X16 FID EPCSI with one measurement, scan time = 28s; (B) 16X16 FID EPCSI with 14 measurements, scan time = 5m40s; (C) 16X16 SE EPCSI with 14 measurements, scan time = 5m40s; (D) 16X16 phase encoding CSI, scan time=5m56s. All scans have 1024 spectral samples and spectral BW = 1350Hz.



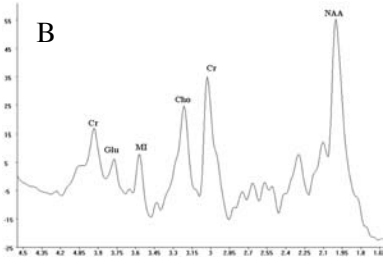


Figure 2: (A) T2 weighted image overlaid with the localized 28s 16X16 FID EPCSI spectral information; (B) Zoom in the spectra from one voxel with 6 clear peaks: NAA (2ppm); Creatine (3.03ppm, 3.92ppm); Choline (3.2ppm); Myo-inositol (3.53ppm); Glutamate (3.76ppm).

Results: Figure 1 shows four spectra from the same voxel of the brain but acquired with four different sequences: (A) FID EPCSI sequence with one measurement; (B) FID EPCSI with Number of Signal Averages (NSA) = 14, scan time 5m and 40s, close to that of conventional 16X16 CSI; (C) SE EPCSI with NSA = 14, scan time = 5m and 40s, TE = 144ms; (D) phase encoding 16X16 CSI with NSA =1, scan time = 5m and 56s, TE = 144ms. No filtering was performed on the four spectra in Figure 1, only offline water suppression. Spectra A and B are from the FID EPCSI sequence. The SNR of B is the expected 3.2 times higher than spectrum A, from the larger NSA used in B. Both spectra A and B have negligible J-coupling effects and T2 decay. Even with significant background noise in A, the six peaks can clearly be seen in both A and B, i.e. NAA (2ppm); Creatine (3.03ppm, 3.92ppm); Choline (3.2ppm); Myo-inositol (3.53ppm), and Glutamate (3.76ppm). C and D are spectra from SE EPCSI and conventional CSI, respectively, both with TE = 144ms and show a lower SNR than B because of the T2 relaxation. Due to the longer TE in C and D, only three peaks can clearly be seen in those two spectra

A Gaussian filter (5Hz) was applied to the in vivo spectra acquired using the 28s FID EPCSI sequence as shown in Figure 2. Figure 2(A) shows the filtered spectra overlaid on a T2 weighted image. Figure 2(B) shows the filtered result of the spectrum shown in Figure 1(A). Based on this 28s FID EPCSI sequence we get a spectrum where at least 6 clear peaks can be seen.

Conclusion: CSI is a valuable method for localized NMR spectroscopy, allowing simultaneous detection of NMR spectra from a large number of voxels. One of the main limitations of the conventional CSI method is its long scan time. By using EPCSI readouts immediately after RF pulse, we were able to both significantly decrease the scan time as well as acquiring localized FIDs. We expect this technique to be useful in other applications, such as breast and liver fat spectroscopic studies.

References: [1] Brown, T.R., Kincaid, B.M., et al, Proc Natl Acad Sci U S A 79, 3523-6, 1982; [2] Mansfield, P., Magn Reson Med 1, 370-386, 1984; [3] Posse, S., Magn Reson Med 33, 34-40, 1995; [4] Tkáč, I., Starčuk, Z., Magn Reson Med 41:649–656, 1999; [5] Zhao, Q., Patriotis, P, et al, Proc ISMRM 2465, 2005.