New CSI Technique Using EPI with Tailored Pulses

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INTRODUCTION: A new spectroscopic technique is introduced that uses chemical shift tagging instead of Fourier Transformation (FT) of spin echo or free induction signals. The time axis is used in the conventional way to form echo-planar images. Spectroscopy data are encoded in a sub-Hz range throughout a time course of EPI acquisitions. Imagine, initially, 128 RF generators tuned in 5 Hz intervals around the Larmor frequency and connected through a combiner to an RF transmitter that tags the entire imaging volume by a single pulse applied before each TR step. In this thought experiment, when the amplitude of each generator is stepped slowly at a different frequency Ω and a crusher pulse between steps is applied, the magnetization of every chemical shift component will vary also. As a result the amplitude in each pixel will vary in time. Because the frequency Ω of oscillations in a given pixel depends only on chemical shifts of its proton contents, the FT of a time course will produce an exact chemical shift spectrum with 128 points and 5 Hz resolution. In the actual method, tailored pulses are created by computer and fed to a modulator that produces exactly the same RF pulse shapes as would occur if 128 separate generators were used. The shape of each pulse through the time course is derived by an inverse FT of the required frequency profile. The amplitude in each spectral segment in a time course varies independently to produce a set of 128 orthogonal harmonics in the Ω range from 128 to 255 oscillations per 512 acquisitions. The modulation flip angles are chosen between 0 and 90 degrees and the amplitude of each segment is varied as arctan[(1 + cos (Ω·t))/2] to achieve sinusoidal modulation of a spectral M_z component. The frequencies in the range of 1 to 127 oscillations are not used, which avoids admixture of second harmonics. Because the phase of Ω oscillations is known, the correlation technique was used for spectral detection (1) to improve the SNR by $2^{½}$. In addition, a correlation coefficient threshold was used to remove spurious signals. CSI reconstruction of the entire time course is done step-by-step for each chemical shift component to correct for EPI shift in the phase-encoding direction. The time series is correlated, pixel-by-pixel, with a known modulation frequency Ω. The resulting image is now centered and represents a single point in a spectrum as shown in Fig. 1.

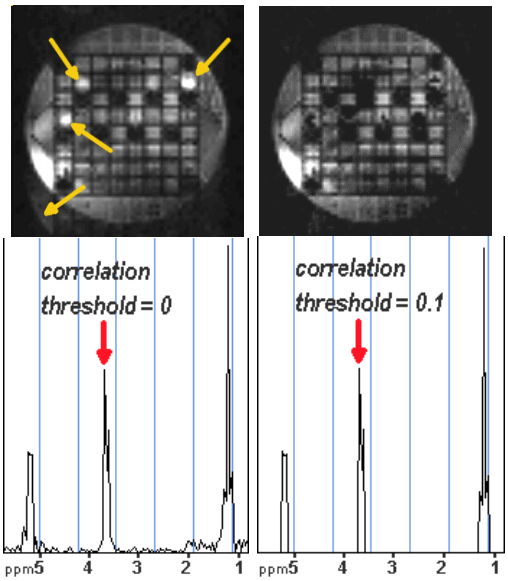

Fig.1 Ethanol spectrum.

METHODS: The study was performed on a Bruker Biospec 30/60 3T MR scanner. A balanced torque three-axis local gradient coil and birdcage RF coil optimized for head imaging were used. Image acquisition and computation of the RF tailored tagging pulses were done off line on a computer equipped with a DATEL PCI-417G2 card, running Linux OS. Two D/A converters on the PCI card were used to create I and Q signals that were fed to a quadrature modulator to produce spectrally modulated tailored pulses synchronously with the EPI sequence. These pulses were mixed with standard RF pulses and sent to the transmitter. Acquisition parameters were: TE=21.8 ms, resolution 64×64, BW=166 kHz, FOV=20 cm, slice 5 mm, TR 0.5 s, tailored modulating pulse time 327 ms, time series: 519 images (512 used). Higher spatial resolutions up to 128×128 were also used. Some spectra with 10 Hz resolution were produced with TR = 0.25 s. Peaks were 3 times weaker than for TR = 1, but spectra were similar.

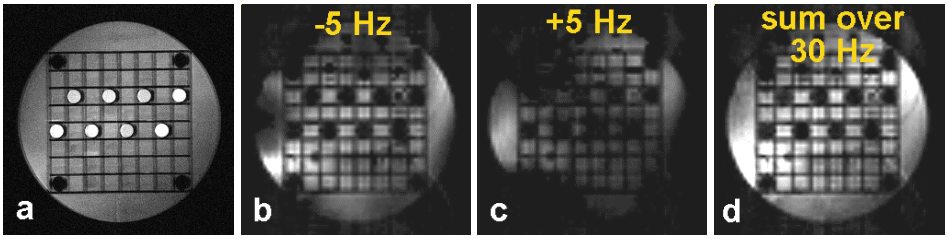

Fig.2 a) Phantom, b & c) Two spectral images 10 Hz apart, d) integral of 1.2 ppm line.

RESULTS: Fig. 1 shows a spectrum from a phantom (Fig. 2a) filled with ethanol and containing, as well, 8 viols filled with water. The left spectrum was processed without the correlation coefficient threshold. Noise appears generally normal but spurious components from water viols are present in the image. The application of a small correlation coefficient threshold removed the artifacts and cleaned the spectrum. As seen from spectral images Figs. 2b and 2c, separated by 10 Hz, shimming influenced the distribution of a signal within an image. The sum of 6 adjacent images, an integral over the width of a spectral line, shows a correct distribution.

DISCUSSION: The use of tailored pulses permits great flexibility in spectral tagging. For example, it would be straightforward to search for the presence of a particular chemical compound, or to determine the ratio of concentrations of two compounds. The correlation method that is central to the CSI strategy introduced here can be expected to yield optimum sensitivity.

REFERENCES: 1. Bandettini PA, Jesmanowicz A, Wong EC, Hyde JS. *Magn. Reson. Med.* **30**(2):161-173, 1993.