Experimental Demonstration of Rosette Spectroscopic Imaging (RSI)

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Introduction:

Monitoring of phosphorous metabolites can be a useful means to study and/or diagnose disease in humans as chronic and/or acute alterations in cell metabolism lead to measurable changes in ^{31}P metabolites that can be measured using ^{31}P magnetic resonance spectroscopy (MRS). However, low concentrations and long T_1's for physiological ^{31}P metabolites impose severe constraints on the spatial resolution and signal-to-noise ratio (SNR) of the images that can be obtained when conventional spatial encoding schemes are used. We demonstrate that Rosette Spectroscopic Imaging (RSI) can be used to obtain images of comparable SNR to conventional acquisition schemes but with significantly lower total acquisition time.

Theory:

The spectral properties of rosette trajectories have been described in [1]. In short, the trajectory consists of a fast oscillation about the origin of k-space that slowly rotates in the K_x-K_y plane. Mathematically they are described by:

$$K(t) = K_{\max} \sin(\omega_1 t) \bullet e^{i\omega_2 t}$$

$$G_{\max} = K_{\max} \bullet \omega_1 / GAM$$

$$S_{\max} = K_{\max} \bullet (\omega_1^2 + \omega_2^2) / GAM$$

$K_{\max}, \omega_1, \omega_2, G_{\max}, S_{\max}$ - are the highest spatial frequency to be sampled, the fast and slow oscillation frequency, maximum gradient and slew rate on the trajectory. When displayed in K-t space (Fig. 1), the sampled data can be seen as an acquisition of multiple spatial planes concurrently with spectral information.

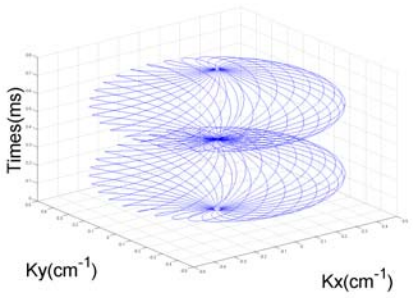

Figure 1: *K-t depiction of a 2D rosette trajectory (2 temporal slices).*

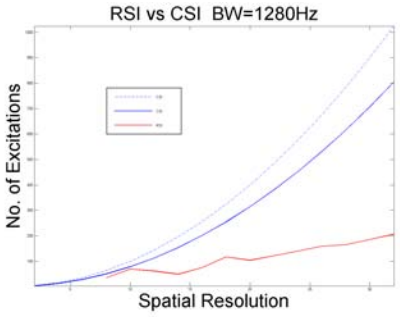

Figure 2: *Number of excitations CSI(blue) vs. RSI (red)*

Methods:

Experiments were carried out on a whole body 3Tesla General Electric scanner ($S_{\max}$ =15000G/cm/s, $G_{\max}$ =4G/cm)**.** Proper K-t space coverage (Nyquist criterion) can be achieved with a significantly lower number of excitations (Figure 2) than in the gold standard chemical shift imaging (CSI) technique. For a desired BW=1280Hz, FOV=24cm and spatial resolution $N_x = N_y = 32$, only 27 shots would be required for ^{31}P MRS imaging versus 1024 excitations for CSI (with no averages or NEX=1, Fig. 2. blue dashed line). To account for the bandwidth increase due to the gradients [2] $\Delta f = \omega_1 N_x / 4 + \Delta\delta$ and to also account for the non-uniform sampling [3], in order to obtain a SNR comparable to CSI, a number of NEX=8 averages (216 excitations) are necessary. Even if the number of CSI excitations can be reduced by a factor of $\pi/4$ (solid blue line) by covering only a disk of radius $K_{\max}$ in K-space, RSI still outperforms CSI. Computer simulations and experimental acquisitions were performed (including in vivo data) to evaluate the performance of RSI. We designed trajectories tailored to each BW and spatial resolution. For ^{31}P imaging typical parameters were FOV=20cm, Nx=14 and RES=4cc.

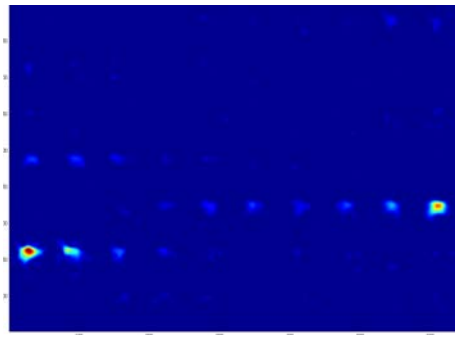

Figure 3: *Spectroscopic Image of a leg of a healthy human volunteer. Displayed (-1000 to 400Hz). Slice Separation 20Hz.*

Results: In vivo data (Fig. 3) was collected for ^{31}P in the leg of a human volunteer. FOV=20cm. Nx=14cm, readout time 65ms, slice thickness 2cm, 32 shots, NEX=2, TR=2s, $\Delta\delta$ =2.4 kHz. Out of the 101 frequency slices reconstructed over a bandwidth of 2.4 kHz, the ones in the range -1 kHz to 400Hz are displayed with a 20Hz separation between them. Besides the central resonance, one can identify 3 other resonance at -800 Hz, -400Hz and at 200Hz.

Conclusions: The increased throughput in data acquisition provided by RSI compared to standard CSI can be used to improve the SNR or it can be used to significantly reduce the total acquisition time for scans that require higher spatial resolution and where the spectral bandwidth is small enough.

References: [1] Noll et al., MRM, **39**, 709, 1998. [2] Pohmann et al., JMR, **129**, 145, 1997. [3] Pipe et al., MRM, **34**, 170, 1995.