MR spectral imaging with 3-dimensional rosette trajectories

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Introduction

The development of hyperpolarization techniques promises to significantly improve the SNR in MR metabolic imaging [1]. Following rapidly evolving changes in metabolism requires fast multi spectral MR data acquisition techniques. FID CSI techniques are generally used to encode spectral/spatial information, but these techniques are not optimal for imaging hyperpolarized signals, having poor spatial and temporal resolution. Intersecting trajectories in k-space are promising in allowing fast multi-spectral data acquisition, and have been previously demonstrated in two dimensions as rosette [2] or stochastic trajectories [3]. While 2D intersecting trajectories are promising as a fast means of obtaining spectro-spatial information in hyperpolarized scans, even more appealing is the isotropic resolution and higher SNR of a 3D sequence. A 2D rosette sequence was expanded to three dimensions, and its spectral selectivity was tested in a single water/fat acquisition. The head of a normal volunteer was scanned using the newly developed pulse sequence, and separate 3D water and fat images were reconstructed from a single 3D MR acquisition.

Methods

A 2D rosette sequence [2] was expanded to 3D and implemented at the proton frequency on a GE 1.5 T scanner. One particular mathematical formulation for 3D rosette-like k-space coverage is described below:

$$k_x = k_{\max} \sin(2\pi f_1) \cdot \cos(2\pi f_2) \cdot \cos(2\pi f_3)$$

$$k_y = k_{\max} \sin(2\pi f_1) \cdot \sin(2\pi f_2) \cdot \cos(2\pi f_3)$$

$$k_z = k_{\max} \sin(2\pi f_1) \cdot \sin(2\pi f_3)$$

Here, f_1, f_2 and f_3 represent frequencies determining the speed of k-space coverage. For multiple shot acquisitions, the trajectories were successively rotated by the angle θ_N, with $\theta_N = 2\pi / N$. Here N represents the number of shots (or arms) needed to cover the k-space. Besides still acting as a spectral filter and allowing data reconstruction at multiple frequencies, this particular implementation of 3D rosettes oversamples the center of each slice in the z dimension without gaps (that, e.g., a cone extension of the 2D rosettes would create). Simulations were performed to insure homogeneous k-space coverage, within the limitations imposed by gradient performance and literature reported brain T_2 values. Optimal acquisition parameters for water/fat imaging in the human brain were found to be f_1=211Hz, f_2=117.3Hz, f_3=73.65Hz, BW=125 kHz, with 16384 samples per arm and 64 arms. These acquisition parameters for a 128x128x16 resolution dataset resulted in a 1.8mm in plane resolution and 2mm slice resolution with a total acquisition time of 32 seconds. Eight arms of the 3D rosette trajectory can be seen in Figure 1a and the coverage of a particular slice of the 3D acquisition is seen in Figure 1b. The 3D rosette requires density compensation before the data are gridded onto Cartesian grids. Due to the intersections within the rosette trajectories, conventional methods did not find an appropriate density function. To pre-calculate the density compensation function (which is critical for obtaining images with good contrast, spatial and spectral resolution), we used a novel non-uniform fast Fourier transform (NUFFT) based iterative algorithm followed by a 3D NUFFT [4] written in MATLAB to reconstruct the images. A typical performance of this pulse sequence *in vivo* is presented from the head of a normal volunteer.

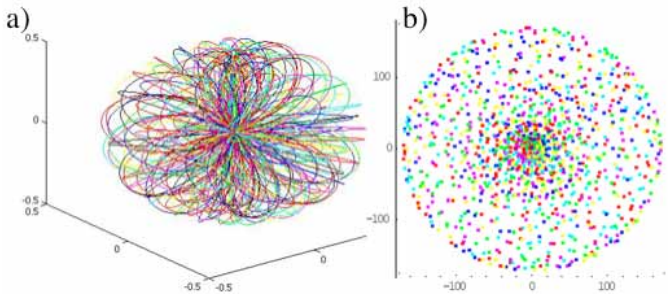

Figure 1: ***a)*** *8 arms of 3D rosette k-space trajectory and* ***b)*** *multi-shot 3D rosette sampling in one slice; each color represents samples from one arm.*

Results and Discussion

Figure 2a and 2b show two slices from the 3D rosette acquisition from a normal volunteer reconstructed at the water frequency and Figure 2c and 2d show the same slices at the fat resonant frequency. To obtain the images in Figure 2, the 3D rosette dataset was reconstructed at every 5 Hz from -30 Hz to +30 Hz from the expected resonant frequencies for both water and fat. A sum of squares image (SoS) was constructed using selected images. For the water image, the +10 Hz and +25 Hz off resonance were used (as the water signal was not perfectly centered in the prescan step), while the -200 and -210 Hz images were used to reconstruct the fat resonance. 3D rosette images, like 2D rosette sequences, are prone to susceptibility artifacts [5], and in the images reconstructed at +10 Hz, a signal void was present in the frontal lobe of the brain due to the B0 inhomogeneity created by the frontal sinus. The signal void was recovered using the off-resonance reconstruction and SoS procedure. Alternatively, a B_0 map can be created from the same data set in a manner similar to [2], and used to correct for off-resonance effects. Such effects should become much less prominent when moving to lower γ nuclei such as ^{13}C. The 3D rosette sequence was very fast; this spectrally selective 128x128x16 dataset was acquired in 32 seconds. Our simulations indicate that an 8cm field-of-view with 5mm isotropic resolution (relevant for hyperpolarized ^{13}C imaging) could be acquired in less than 6 seconds on a clinical scanner, using the 3D rosette.

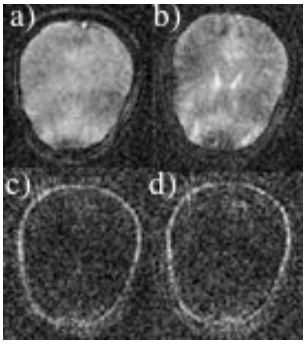

Figure 2: *3D rosette water (**a**) and (**b**) and fat images (**c**) and (**d**) reconstructed from 2 different slices from the brain of a normal volunteer.*

Conclusion

Fat and water images of the brain of a normal volunteer were successfully acquired and reconstructed using a 3D rosette sequence that we developed. Fast acquisition time is essential for imaging hyperpolarized compounds, and the combination of fast acquisition time, spectral selectivity and spatial resolution makes the 3D rosette sequence promising in its application to *in vivo* hyperpolarized ^{13}C.

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