Fast EPR Imaging Using Spinning Magnetic Field Gradient

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INTRODUCTION

Electron paramagnetic resonance imaging (EPRI) has achieved remarkable progress in the last decades and has many useful and unique applications in the fields of biology and medicine [1-3]. However, the long imaging time prevents the use of this technique in many biological applications where the free radicals have a short intrinsic lifetime or rapid metabolic clearance. Therefore, there is a great need to develop fast EPRI techniques [4, 5]. In this study, we report the development of a fast low-frequency EPRI system using spinning magnetic field gradient (SMFG).

EXPERIMENT

Estimation of the Minimal Number of Steps of Field Sweep

In the SMFG technique, the imaging time is proportional to the number of steps of field sweep [4]. Considering the acquisition of the zero-gradient projection in EPRI, the minimal number of steps of field sweep is determined by the band width of the zero-gradient projection according to Shannon's sampling theorem. We estimated this minimal number by investigating the sampling error of the simulated noise-free zero-gradient projection to be between 64 and 128.

Hardware Implementation

In our EPRI system, a personal computer equipped with a PCI-488 GPIB board (Capital Equipment Corporation, MA) and three KPCI-3108 boards (Keithley Instruments, Inc., OH) is used to control the data acquisition process and image reconstruction. The KPCI-3108 boards generate the field sweep signal and the gradient waveforms. For synchronization purpose, all the three boards are programmed to use the external clock which is generated through the internal timer 1 and 2 (cascaded) of the board 1 (See Fig.1). The pacing frequency for D/A and A/D conversion was 10 kHz in our experiments. Before starting an imaging experiment, the field sweep signal and the gradient waveforms are calculated according to the imaging parameters and stored in a chain of buffers which are accessible by the KPCI-3108 boards. The stored field sweep signal and gradient waveforms are then output to drive the main magnetic field power amplification and the gradient power amplification, respectively. In the meantime, the EPR signal (coming from the analog output of the Bruker signal channel) is sampled at 10 kHz and stored in the computer for further post-processing. In SMFG, the complex impedances of the gradient coils need to be taken into account to compensate the gradient strength.

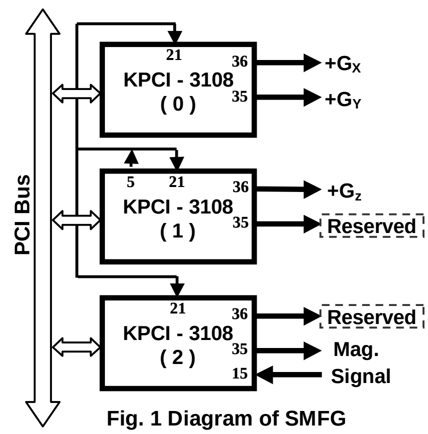

Fig. 1 Diagram of SMFG

Data Processing and Image Reconstruction

After data acquisition, all the pseudo projections are smoothed and re-ordered to get the normal projections. The number of projections after data re-ordering equals the length of a pseudo projection. To reduce the time for data post-processing and image reconstruction, we down-sample each pseudo projection by 2 and make the projection number odd [4]. As in a regular EPR imaging experiment, both the zero-gradient projection and normal projections are acquired. Then, the automatic deconvolution algorithm [6] will be applied to deconvolve the projections before the filtered back-projection algorithm is performed for image reconstruction.

RESULTS

Based on a 300 MHz conventional EPRI system, we have implemented a 2D fast EPR imaging system using SMFG, and tested it by imaging a phantom object which was a bottle (26 ml) of 1 mM TAM in half-water and half-saline solution. For comparison, we conducted both regular and fast EPR imaging experiments on the same phantom. The imaging parameters were as follows: scan width (SW) = 1.2 mT; field of view (FOV) = 80x80 mm^2; modulation amplitude (MA) = 0.05 mT. In the regular imaging experiments, time constant (TC) = 10 ms and scan time (ST) = 2.6 s, while in the fast imaging experiments, TC = 0.64 ms. The imaging results are shown in Fig. 2. Fig. 2A and 2B were acquired using the regular technique with imaging time as 21 s and 84 s, respectively, while Fig. 2C and 2D were acquired using SMFG with imaging time as 5 s and 21 s, respectively. The spinning frequencies in Fig. 2C and 2D were 12 Hz and 6Hz, respectively, and the number of steps of field sweep was 64 and 128, respectively. From Fig. 2, it can be seen that Fig. 2C (fast, 5 s) is better than Fig. 2A (regular, 21 s) and Fig. 2D (fast, 21 s) is close to Fig.2 2B (regular, 84 s) in terms of image quality. In summary, we have implemented the fast imaging system and demonstrated the feasibility of using the SMFG technique for fast EPR imaging at low frequency.

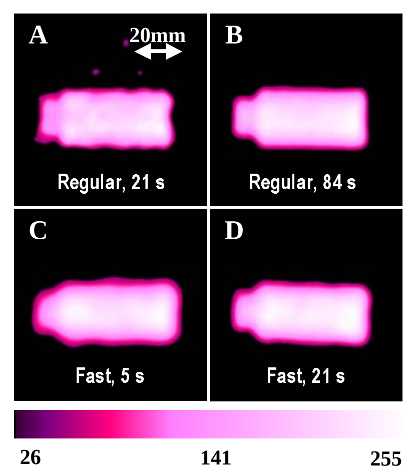

Fig. 2 Imaging results

CONCLUSIONS

We have built a 2D fast EPR imaging system using spinning magnetic field gradient, which is capable of acquiring a 2D image in about 20 s with reasonable image quality. This is 2-4 times faster than regular EPRI acquisition. In future work, we will apply this technique to biological applications and continue to develop a 3D fast EPR imaging system.

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