Fast 3D EPR Imaging Using Spiral Magnetic Field Gradient

Y. Deng[1], S. Petryakov[1], G. He[1], E. Kesselring[1], P. Kuppusamy[1], and J. Zweier[1]

[1]Davis Heart and Lung Research Institute, Department of Internal Medicine, The Ohio State University, Columbus, OH, United States

Abstract

We report a fast 3D continuous wave (CW) electron paramagnetic resonance imaging (EPRI) technique using spiral magnetic field gradient. By spiraling the magnetic field gradient and stepping the main magnetic field, this approach acquired a 3D image in one sweep of the main magnetic field, enabling significant reduction of the imaging time. We demonstrated using a home-built L-band EPR system that the spiral magnetic field gradient technique enabled a 4 to 7-fold accelerated acquisition of projections compared to the conventional stepped gradient projection acquisition.

Introduction

The CW EPRI technique has been widely used in a variety of medical applications. However, due to the nature of magnetic field sweep, it requires long image acquisition periods and this limits its use for many *in vivo* applications where relatively rapid kinetics occur. Therefore, there has been a great need to develop fast EPRI techniques. We report the development of a fast 3D CW EPRI technique using spiral magnetic field gradient.

Methods & Materials

In conventional 3D CW EPRI, projections are acquired through 3-layer nested loops with the inner loop for field sweep and the outer two loops for gradient angles. The slow field sweep process is repeatedly carried out during projection collection. To avoid this problem, the field sweep loop was placed as the outer loop, as previously reported (1) for 2D fast EPRI. A pseudo projection was then acquired by fixing the magnetic field and continuously changing the gradient angles. As a result, a 3D image was acquired with one field sweep. All the pseudo projections were smoothed, down-sampled and re-ordered to form normal-mode projections. A direct one-stage 3D image reconstruction algorithm was modified to reconstruct the EPR images from the projections acquired with the spiral magnetic field gradient (2). The L-band imaging system is similar to our 300 MHz imaging system (1). The gradient waveforms and the field control signal, shown in Fig.1, were generated using three high-performance data acquisition boards (KPCI-3116, Keithley Instruments, Inc., OH). The EPR signal was also sampled at 10 kHz using the analog input channel of one KPCI-3116 board. The phantom was constructed using 7 syringe tubes (id = 4 mm) after removal of the metal needle. Each tube was filled with 0.2 ml of 2 mM trityl solution. The peak-to-peak linewidth of the trityl solution in room air was 19 µT at L-band. In both regular and fast imaging experiments, the scan width = 1.6 mT and FOV = 40x40x40 mm^3, resulting in a gradient strength of 40 mT/m. The incident microwave power was 40 mW. The modulation frequency was 100 kHz and the modulation amplitude was 20 µT. The time constant was 5 ms for the regular data acquisition and 0.64 ms for the spiral data acquisition in the experiments. In the regular imaging experiments using stepped gradients, the main magnetic field was swept continuously and a fixed length of 1024 points was acquired for each projection. The shortest scan time was 2.6 s and 0.1 s delay between scans was also used. Deconvolution was performed before image reconstruction in both regular and fast imaging experiments.

Results

The regular images are shown in Figs. 2A-D. The projection number for images 2A-D was 144, 256, 400 and 576, respectively. The imaging time was 392, 696, 1088 and 1567 s, respectively. Figs. 2A'-D' show the results of fast imaging. The number of steps of field sweep was 128 and the spiral frequency pair (transverse component frequency vs. longitudinal component frequency) were 24.39 (0.554), 24.10 (0.287), 12.05 (0.143) and 12.27 (0.075) Hz, respectively. The imaging time was 58, 111, 223 and 428 s, respectively, within which 451, 1743, 1743 and 6683 projections were acquired. To quantitatively compare the image quality, the signal-to-noise ratio (SNR) for each 3D image was calculated and was 7.7, 10.9, 18.1, 30.2, 16.5, 22.4, 26.4 and 29.3 for images 2A-D and 2A'-D', respectively. The SNR was defined as the mean of the signal (>10% of the maximum signal intensity) divided by the standard deviation of the noise (non-signal but greater than 0).

Conclusion

We implemented a fast 3D continuous wave electron paramagnetic resonance imaging technique using spiral magnetic field gradient. We demonstrated using a home-built L-band EPR system that the spiral magnetic field gradient technique enabled a 4 to 7-fold accelerated acquisition of projections compared to the conventional stepped gradient projection acquisition.

Reference:

1. Y. Deng, G. He, S. Petryakov, P. Kuppusamy, and J. L. Zweier, Fast EPR imaging at 300 MHz using spinning magnetic field gradients, J Magn Reson 168, 220-227 (2004).
2. Y. Deng, P. Kuppusamy, and J. L. Zweier, Progressive EPR imaging with adaptive projection acquisition, J Magn Reson 174, 177-187 (2005).

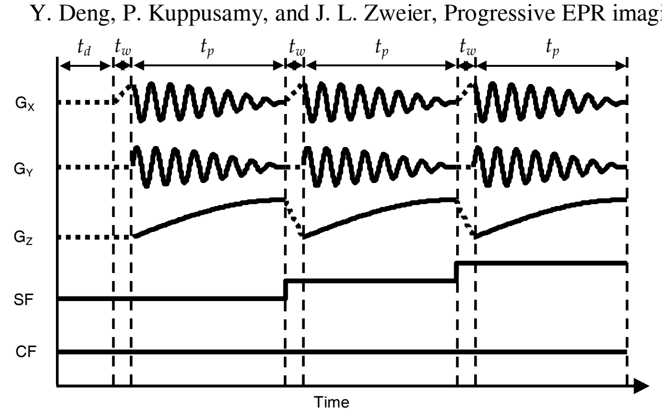

Fig. 1 Waveforms for magnetic field gradients and main magnetic field

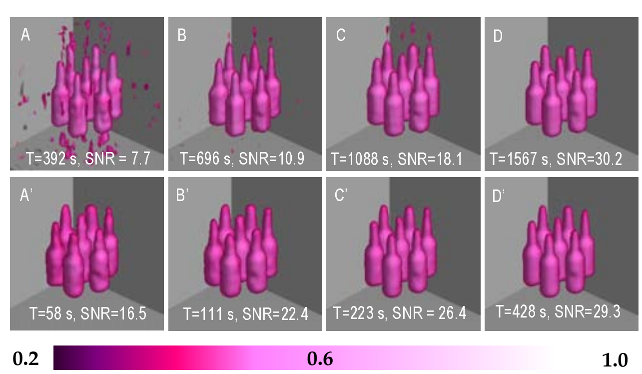

Fig.2 Imaging results of Trityl phantom