Slice selection using modulated gradients for Fast 2D Single Point EPR Imaging

N. Devasahayam[1], S. Subramanian[1], S. Matsumoto[1], and M. C. Krishna[1]
[1]Radiation Biology, National Institutes of Health, Bethesda, MD, United States

Introduction: Electron Paramagnetic Resonance Imaging (EPRI) is emerging as a powerful molecular imaging tool in small animals to map tissue pO_2 using novel contrast agents such as the trityl radicals which are non-toxic and display simple EPR spectra with T_2s in the range of 1-5 microseconds depending on tissue oxygen levels. Time-domain image data acquisition techniques have been implemented for in vivo EPRI at 300 MHz [1]. However the image data was collected using static gradients using the single point imaging (SPI) modality. In this modality, for a 3D image data, typically a set of n^3 (n x n x n) gradient settings in a Cartesian raster is collected to examine voxel based pO2. Modalities which allow the collection of 'm' slices of n x n (n^2) data greatly reduces the time needed for image data collection [2]. It was suggested in 1974 that with time-dependent inhomogeneous component to static magnetic field it is possible to retrieve spatial information[1]. Subsequently it has been shown that modulated field gradients can be used to obtain image information from a selected location of the subject. Sato-Akaba et al.[2] have demonstrated the possibility of slice-selected 2D image using CW EPR. We have incorporated this approach of slice-selection using sinusoidally modulated gradients to collect 'm' slices of n x n images that can greatly reduce the measurement time and can thus allow improvement in the SNR and resolution in the selected slices without additional measurement time.

Method and Results: We employ the single point imaging scheme [3] by which two and three dimensional in vivo EPR imaging and relaxation based oxymetry have been carried out routinely in our laboratory. In this development we use the same imaging equipment operating at 300 MHz, with an additional provision of applying a low frequency (100 Hz) sinusoidal field along one of the gradient axes at nominal AC amplitude of about 1 mT/m. The modulation of the gradient along a particular axis introduces inhomogeneity along that axis everywhere except around the midpoint at which the amplitude is close to zero. A two dimensional phase encoding in a plane perpendicular to the axis of the modulated gradient retains coherent phase information only from the narrow slice at the center with spin distribution on either side of the slice undergoing total loss of coherence and does not contribute to the detected signal.

As a proof od principle experiment we made a phantom consisting of three tubes(4 mm i.d) filled to different levels with 3 mM Oxo63 (a stable trityl radical with a narrow single ESR absorption) and placed at a spacing of 15 mm as shown in Fig.1. Two dimensional images were obtained by single point imaging with a maximum gradient of 15mT G/m along the three planes YZ, XZ and XY and are shown in the top row. When we carryout the 2D phase encoding in the XY plane with the Z-gradient being modulated at 100 HZ at amplitude of about 10mT/m we see only the tube centered at z-coordinate of zero (Fig. 2D). The other two tubes do not produce any signal due to the inhomogeneity imposed by the modulated z-gradient. By shifting the resonator such that the other tubes are brought to the centre sequentially, we could get slices exclusive images of them. In this first-principle experiment, we could easily get a slice resolution of about 5 mm and slice thickness of 5 mm.

Discussion and Conclusions: For the first time, a slice selection approach in Time-Domain EPR imaging has been demonstrated using sinusoidal gradients of 100Hz frequency and 1G amplitude to select slices of ~5 mm. With this the imaging time has been reduced from 17 minutes for an 21 x 21 x 21 3D data set to just 48 sec. per slice of 21 x 21 data set, with out sacrificing resolution. Additionally, it will be possible to improve the dynamic range by avoiding slices containing high-content of the probe such as the bladder from overwhelming the images in other slices as is the case in volume imaging 3D data sets. Optimization of the amplitude of the oscillatory gradient and its frequency may lead to better slice definition. Instead of physically moving the resonator to bring various slices to the gradient center, an offset in the oscillatory gradient location can also be used to select the slice location. This will enable obtaining slice-selected 2D EPR images that exactly corresponds to 2D slice images of MRI, from the same resonator, for better co-registration

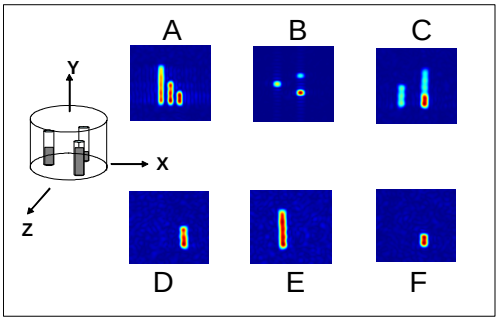

Fig.1 A three-tube phantom is shown on the left. The three tubes contain 3 mM Oxo63 at different levels and are placed at different z-co-ordinate locations. The top row images show the normal 2D SPI images taken with phase encoding along YZ, XZ and XY planes showing the projections along these planes. The max. gradient was 15 mT/m and the number of steps were 21 x 21 (441 k-space points). The bottom row shows 2D XY images obtained when the Z-gradient was modulated at 10 mT/m amplitude at 100Hz frequency. Only the tube at the center of the gradient axes (Z-coordinate =0) is encoded and produced the image. By properly positioning the resonator it was possible to get exclusive images of each tube enabling slice selection. The slice thickness and resolution were ~5 mm.

References:

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