

# High Resolution EPR Imaging and $T_2$ -based Oximetry Using a Combination of Spin-Echo and Single Point Imaging

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## Abstract

Electron spin resonance imaging and oximetry methods are being developed as an adjunct to other imaging modalities such as CT and MRI in diagnostic radiology and functional imaging. ESR imaging is perhaps the only method that has the promise of providing quantitative three dimensional mapping of oxygen in vivo. 3D oximetry is important in oncology since hypoxic regions of tumor are 3 to 4 time more resistant to both radiation and chemotherapeutic treatment. In this work we describe a novel combination of spin-echo and constant time pure phase-encoding modality (also known as Single Point Imaging, SPI) of imaging and oximetry that provides both high resolution spin imaging and accurate oximetry.

## Introduction

We describe an EPR imaging modality that provides high resolution spin images and accurate oximetry maps in phantoms and in vivo. Frequency encoding methods based on projections obtained from the FT of FID or echo acquired under gradients followed by filtered back-projection methods have been the earlier methods of choice. Pure phase encoding of a constant time point in the FID and reconstruction of the images by FT (Single Point Imaging, SPI) leads to line-width independent high resolution images. For generating spatially resolved spectroscopic imaging in the time domain one can use  $T_2$  weighting in the case of echo-based imaging by varying the echo-time TE, and  $T_2^*$  weighting in the case of SPI, by using successive time-points in the FID. The images from echo-based technique have resolution limited by line width and susceptibility artifacts. Those from SPI are very good in resolution, but are somewhat affected by  $T_2^*$  dependence on gradient magnitude, resonator size and filling factors, requiring specific calibration for oximetry. The echo-based method on the other hand provides resonator & gradient independent oximetry. The obvious choice therefore is to use the SPI strategy in which the time points that are used for phase encoding are at equal time intervals on either side of the refocusing pulse of a spin echo experiment. In other words a combination of the SPI and Spin-echo mode provides the dual advantage of high resolution and  $T_2$ -based oximetry.

## Experimental, results & discussion

Single Point imaging schematics is shown in Fig.1. The method consists of phase encoding a single time point of an FID with constant gradients which are then rastered in Cartesian frame in two or three dimensions that generates a pseudo echo similar to the gradient-recalled echo mode of MRI. The k-space thus generated upon n-dimensional FT provides the image. Since the image data comes from single time point at a constant delay from the excitation pulse, all other time-dependent evolutions do not modulate the phase, except the gradient dependent frequencies. This leads to line-width independent highly resolved images. Spectral information is introduced by generating a series of  $T_2^*$  weighted images obtained from a sequence of time points. Unfortunately  $T_2^*$  is not an intensive property and depends on gradient magnitude and the resonator size, image bandwidth etc. If one resorts to perform imaging and oximetry from  $T_2$ -weighted spin-echo profiles one can get reliable spatially resolved spectral information, but the images, however, are governed by  $T_2^*$  for resolution. A combination of echo and SPI provides the high resolution advantage of the pure phase-encoding modality of the SPI and when these single points have a refocusing  $\pi$  pulse in between then one can introduce pure  $T_2$ -weighting in the contrast/intensity. Echo-based SPI thus produces excellent images and quantitative oximetry as demonstrated in the figures below.

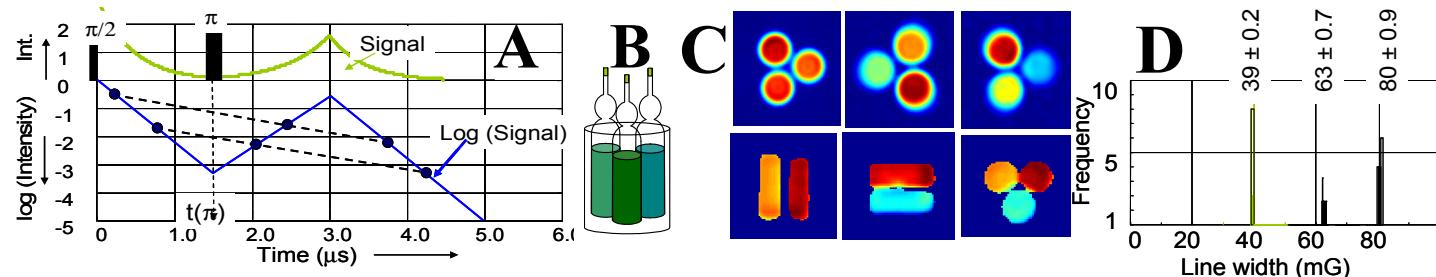


Fig.1 A. Schematics of the spin-echo based SPI imaging. The single points marked on bold circles undergo decay according to  $T_2$  and images derived from these time points under phase encoding gives resolved images of identical FOV, and one can evaluate spatially resolved  $T_2$  and hence perform in vivo oximetry. B. 3-tube phantom containing Oxo63 (trityl) saturated with 0%, 1.9% and 5% oxygen. C. Spin images (top row) and oxygen images (bottom row) on a few selected slices from a 3D image. D. Histogram of oxygen distribution from the three tubes showing excellent resolution and accuracy of oxygen-dependent line width.

In vivo measurements on mouse models of tumor shows that the echo-based SPI imaging modality can produce 3D volume spin images and oxygen maps, both with excellent resolution in less than 5 minutes. Co-registration of ESR spin and oximetric images with MRI/CT anatomic / metabolic images can provide information on the impact of tumor hypoxia on tumor metabolism and drug action.

## References

- (1) E. D. Barth et al. *Magn. Reson. Med.* 2003. 49(4): p. 682-691.
- (2) K. Matsumoto et al. *Magn. Reson. Med.* 55 (5): 1157-1163 (2006)
- (3) S. Subramanian et al. *In Vivo Tissue Oxygen Imaging Via Cooperative ESE/ESPI* - US Patent app. # 61/200,579.