Oxymetric Imaging in EPR: Single Point Imaging versus Two-Pulse Echo Imaging

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Abstract

Radiofrequency Electron Paramagnetic Resonance Imaging, RF-EPRI is an emerging technique that is capable of providing functional physiological information such as quantitative in vivo oxygen distribution and tissue red ox status in a non-invasive manner. EPR imaging is perhaps the only modality to provide these non-invasively. When co-registered with functional and anatomical MRI, EPRI can provide valuable and complementary information that may be very useful in treatment planning and assessing treatment outcome in radiation and chemotherapeutic treatment of cancer. However, in order to be effective it is important that the EPR imaging measurements are done at times on the order of the corresponding MRI measurements to prevent unacceptable temporal and spatial averaging due the fast dynamics of spin perfusion, pharmacokinetic and metabolic clearance. Therefore one would resort to time domain modalities of imaging in EPR. While is it indeed a challenge to design instruments that can deal with dynamics of sub-microsecond scale that would mandate timing resolution of nanoseconds and data acquisition rates on the order of several hundred Ms/s, with advances in electronics and computational capabilities several laboratories have come up with time-domain EPR imaging instruments and modalities. In this work we compare the relative sensitivities of two time-domain approaches to spatial and spectral-spatial imaging, namely the so-called single point imaging (SPI) with pure phase-encoding & Fourier reconstruction, and the two pulse echo modality with filtered back-projection using frequency encoding (Echo-FBP).

Summary

Non-invasive functional imaging techniques are becoming important in the diagnosis, treatment-planning and the assessment of treatment out come especially in clinical oncology. In Electron Paramagnetic Resonance Imaging, non-toxic paramagnetic spin probes are introduced in to the imaging subject and the spatial distribution and spatially resolved spectroscopic information gleaned by EPR imaging can provide, in a non-invasive manner, quantitative information on tissue oxygenation, as well as tissue redox status among other physiological parameters such as pharmacokinetics, perfusion dynamics, etc. EPR imaging can be carried out both in the continuous wave (CW) and the time-domain (FT-EPR) mode. In this work we focus essentially on time-domain approaches. There are basically three ways of time-domain data collection and image processing in FT-EPR. (**1**) FID-FBP: One can obtain the time-domain responses in the form of FIDs which results from pulsed excitation and subsequent Fourier transformation to obtain projections in the presence of gradients and perform filtered back-projection to obtain images of spin distribution. Here, large gradients used to improve spatial resolution lead to rapid loss of sensitivity due to substantially reduced transverse relaxation time (T_2*) and *is no longer considered a practical approach.* (**2**) Echo-FBP[1]: To circumvent sensitivity loss and to perform T_2-weighted imaging to get spatial and spectral information co-registered, one can use the conventional two-pulse spin-echo procedure where the decay of the impulse responses are covered by T_2 and a sequence of T_2-weighted images can provide spectral information. In (1) & (2) spatial information is frequency encoded in presence of constant gradients. (**3**) SPI[2]: A Third alternative is to use single point imaging SPI, where image data is derived from a single time point after the pulse in presence of static phase-encoding gradients followed by Fourier reconstruction that provides images unaffected by the line width or relaxation times. Here one can reintroduce spectral information by examining the images processed at sequence of points with progressive delays from the pulse. Upon proper calibration of T_2* using standard samples one can extract reliable spectral information.

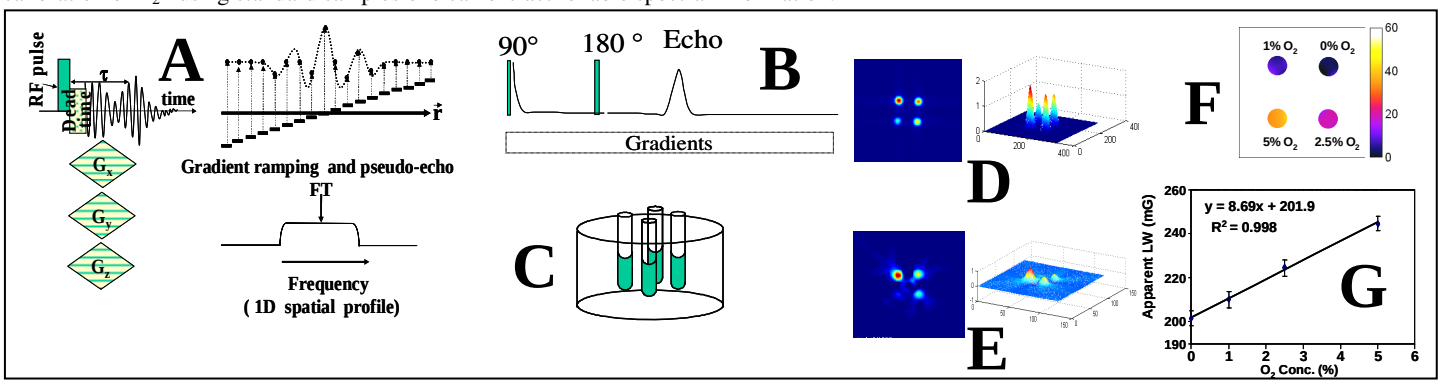

Fig.1, Schematics of (A) the SPI imaging and (B) the two pulse Echo imaging. In the former a single time point is phase encoded by increasing the gradients in steps, whereas in B the spin echo is subjected to frequency encoding in presence of constant gradients. (C) A four-tube phantom of 500 µL aqueous solution 3mM trityl radical equilibrated with oxygen concentrations 0, 1, 2, & 5%. (D) Single Point 2D image obtained with maximum gradient of 0.8G/cm applied in increments of 0.08G/cm along the transverse directions in a looped fashion, and reconstruction via FT. 10,000 FIDs averaged per gradient setting. (E) 2D image and mesh profiles obtained by averaging 10,000 echoes following 90°-τ-180°pulse-pair with 0.8 G/cm gradients, applied and rotated in 10deg. steps in a plane perpendicular to the tube axes, followed by FT and filtered back-projection. Note the overall gradient induced broadening and that the 5% pO2 tube just barely shows up due to the broader line width (F) Color-coded oxymetric images obtained from a set of three gradients (0.8,1.0 and 1.2) and the corresponding T_2* from each tube. (G) The plot of the apparent line width vs. pO_2 showing very good linearity from the SPI experiment.

Our results show that SPI and Echo-FBP procedures provide reliable spectral and spatial information and hence in vivo pO_2. *SPI methodology is nearly an order of magnitude faster than the two-pulse echo approach in imaging time for a given image SNR*, but requires careful calibration of the T_2* versus pO_2 for a given gradient range and resonator. The Echo procedure, on the other had deals with T_2 and hence pO_2 estimates are straightforward. SPI T_2* dispersion was found to be much larger than that of T_2. *Spatial and oxygen resolution, therefore, are far superior in the case of SPI.*

Reference

1. Colin Mailer et al. Magn. Reson. Med. **55**:904–912 (2006) **2**. S. Subramanian, et al. Magn. Reson. Med. **48** 370-379 (2002)