A method to improve temporal resolution in EPR imaging of tissue oxygenation

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Purpose

Electron paramagnetic resonance imaging (EPRI) has emerged as a highly specific modality to dynamically image tissue oxygenation. Due to extremely short spin-spin relaxation times, EPRI benefits from the use of single point imaging (SPI) schemes where an entire FID is acquired under constant gradients.[1] Although the SPI scheme is advantageous for improving image quality, resultant time decreasing field of views (FOVs) inhibit direct calculation of spectral linewidth (which is calibrated to tissue pO_2). Therefore, conventional acquisition techniques require repeated imaging experiments with differing gradient amplitudes (typically 3) to calculate pixel-wise linewidth (or T_2^*).[2] In this work, we compare the use of gridding and image-based registration techniques to maintain FOV and enable direct calculation of oxygenation from a single dataset thereby potentially increasing temporal resolution for dynamic imaging studies by a factor of 3x.

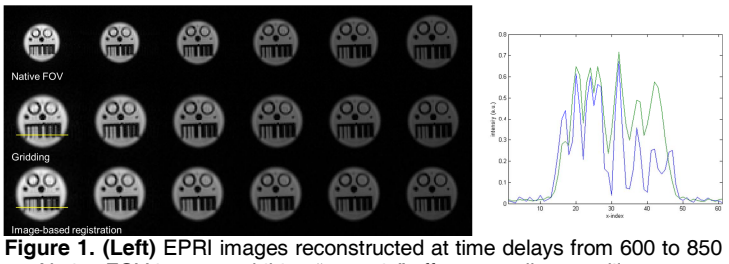

Figure 1. (Left) EPRI images reconstructed at time delays from 600 to 850 ns. Native FOV images exhibit a "zoom-in" effect as well as readily apparent T_2^* decay. Gridding and image-based registration techniques allow FOV to be maintained. **(Right)** 1D Profile through yellow line shows improved resolution for Gridding (Blue) versus Image-based registration (Green).

Time Range (ns)	Image-based Reg. Linewidth Fit	R^2	Gridding Linewidth Fit	R^2
950-1150	4.925 mG/%O_2 [%O_2] + 238.5 mG	0.9847	5.030 mG/%O_2 [%O_2] + 241.7 mG	0.9741
750-1150	4.792 mG/%O_2 [%O_2] + 236.7 mG	0.9988	4.706 mG/%O_2 [%O_2] + 237.0 mG	0.9997
550-1150	3.567 mG/%O_2 [%O_2] + 254.4 mG	0.9994	3.848 mG/%O_2 [%O_2] + 246.8 mG	0.9900

Table 1. Linewidth fit for %O_2 using gridding and image-based registration methods. Fitting across a range of 750-1150 ns provided the best fit. Both methods provided high coefficients of determination.

Methods

For SPI datasets $FOV = 2\pi/\gamma_e \tau \Delta G$. Thus, as time ($\tau$) increases, the FOV decreases. For image-based registration, the necessary scaling factor was calculated based on the equation above and an affine transformation was applied to the data using cubic interpolation. For gridding, standard convolution gridding methods were employed.[3] While scaling the inter-sample distance in *k*-space allows the FOV to be maintained, spectral leakage and resultant aliasing occurs if phase encoded points do not fall at integer intervals along the Cartesian grid. Therefore, we continuously decrement the gridding factor (α) by the FOV scaling factor to obtain aliasing-free images. Image quality was evaluated using a resolution phantom imaged with 61x61 phase encoding points, sampling each FID for approximately 2,500 ns with 5 ns sampling rate. To test quantitative measurements using these methods, a four-tube phantom composed of 3 mM Oxo63 solutions bubbled with different oxygen concentrations (0%, 1%, 3%, 5%). Images were acquired with 23x23 phase encoding points G_{max}= 0.96 Gauss/cm. The methods above were used to construct a series of images. Pixelwise linewidth is directly calculated by fitting a Lorentzian lineshape to the Fourier transform of the T_2^* decay curve using non-linear least squares across varying time ranges.

Results

Figure 1 shows resolution phantom images reconstructed from time points 600 to 850 nanoseconds using the methods described above. Figure 2 shows the tube phantom image at time delay 1150 ns, along with a fitted T_2^* decay curve. Table 1 lists the estimated fit for linewidth and pO_2, which were estimated using regridding and affine transform method respectively.

Discussion

Both methods show potential for improving temporal resolution by allowing quantification of linewidth from a single dataset. As seen in Table 1, high coefficients of determination for the oxygen concentrations are attained regardless of method; however, Figure 1 shows that gridding better preserves high-resolution details. For both methods, there exists a trade off between mitigating blurriness (minimizing interpolation between the first and last time delay images) and a sufficient number of temporal images to accurately measure linewidth. This method may also have potential to minimize gradient-amplitude-dependent confounds for the linewidth of the EPRI spin probe. Future work will utilize these techniques to improve the temporal resolution (or spatial resolution with equivalent temporal resolution) for *in vivo* tumor hypoxia imaging.

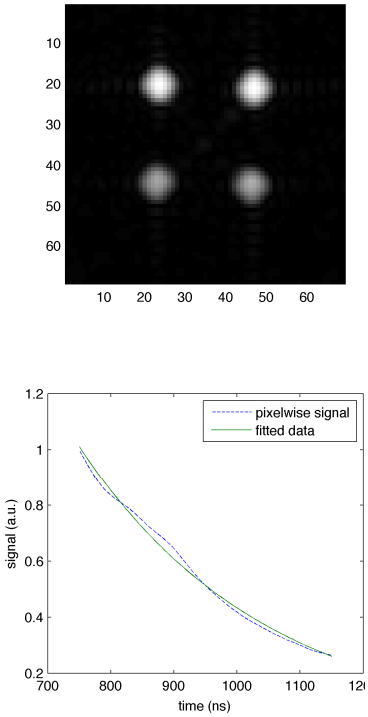

Figure 2. (Top) Tube phantom image reconstructed at time delay 1150 ns. **(Bottom)** (Blue dashed line) Signal from a single pixel in the 0% O_2 tube showing good fit (Green line) with the fitted linewidth/T_2^*

References

1. Subramanian et al. (2002). MRM. 48: 370–379.
2. Matsumoto et al. (2006). MRM 55:1157-1163.
3. Beatty et al. (2005). IEEE Trans Med Imag. 24:799-808.